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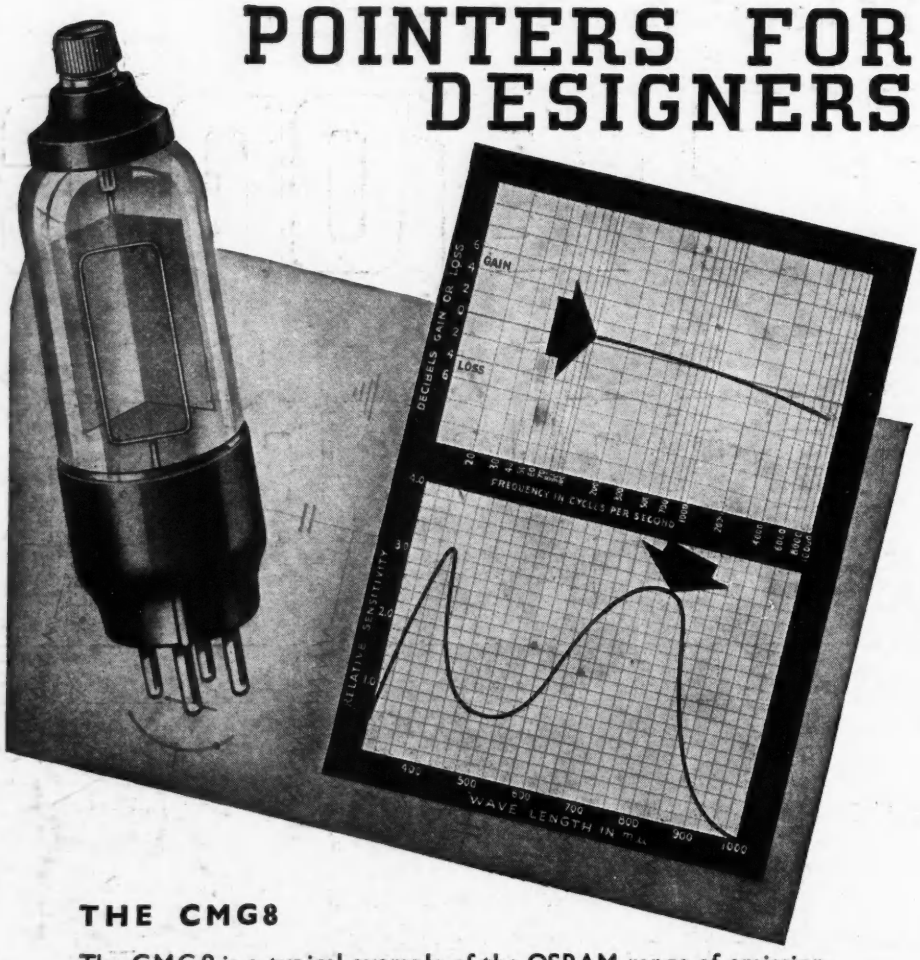

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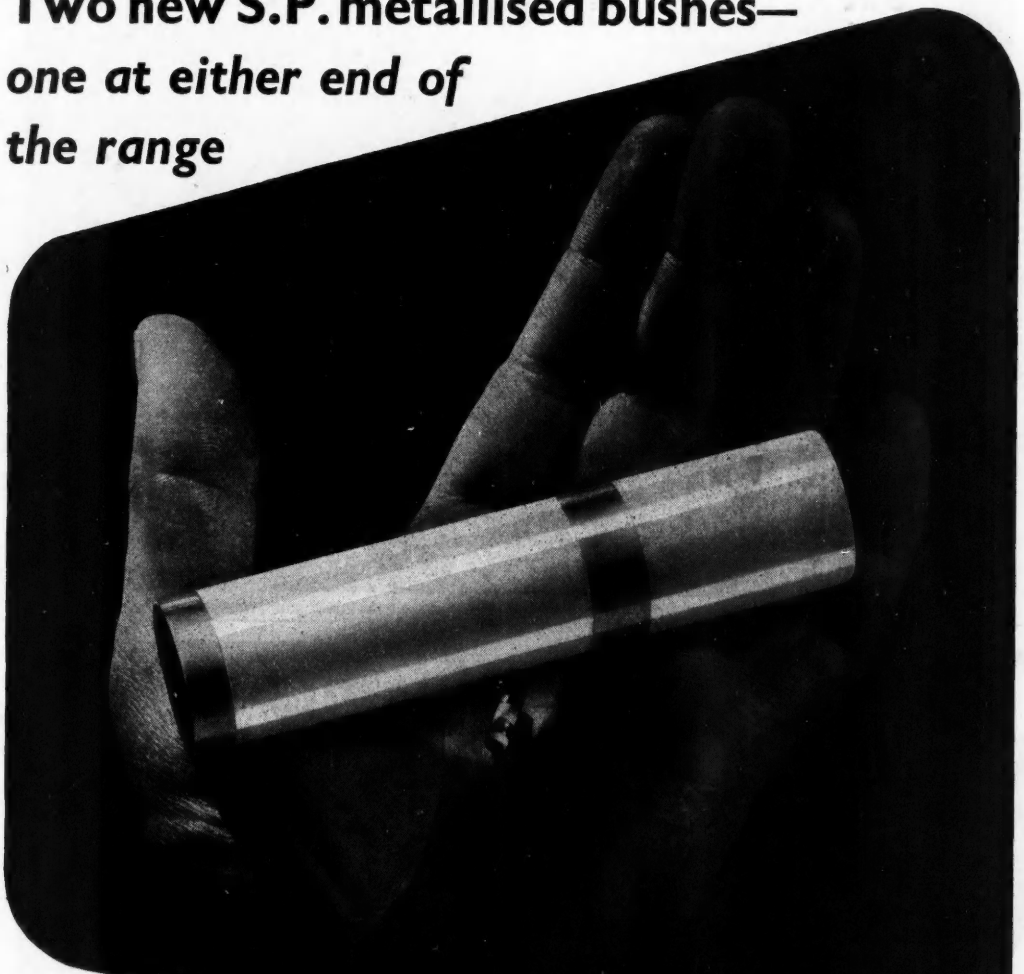

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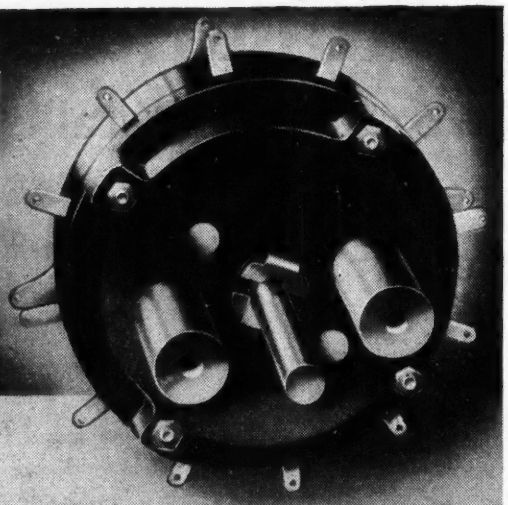

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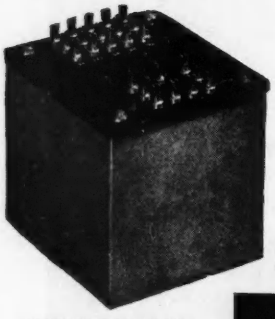

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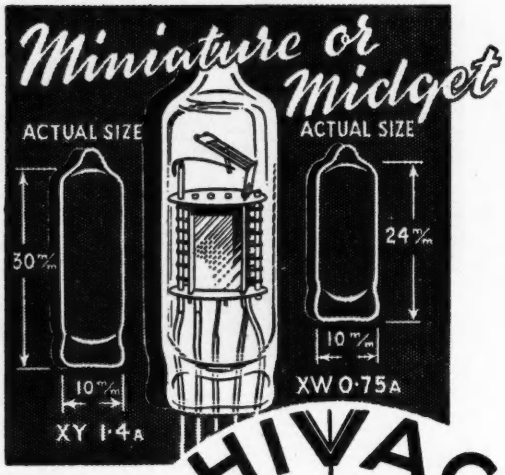

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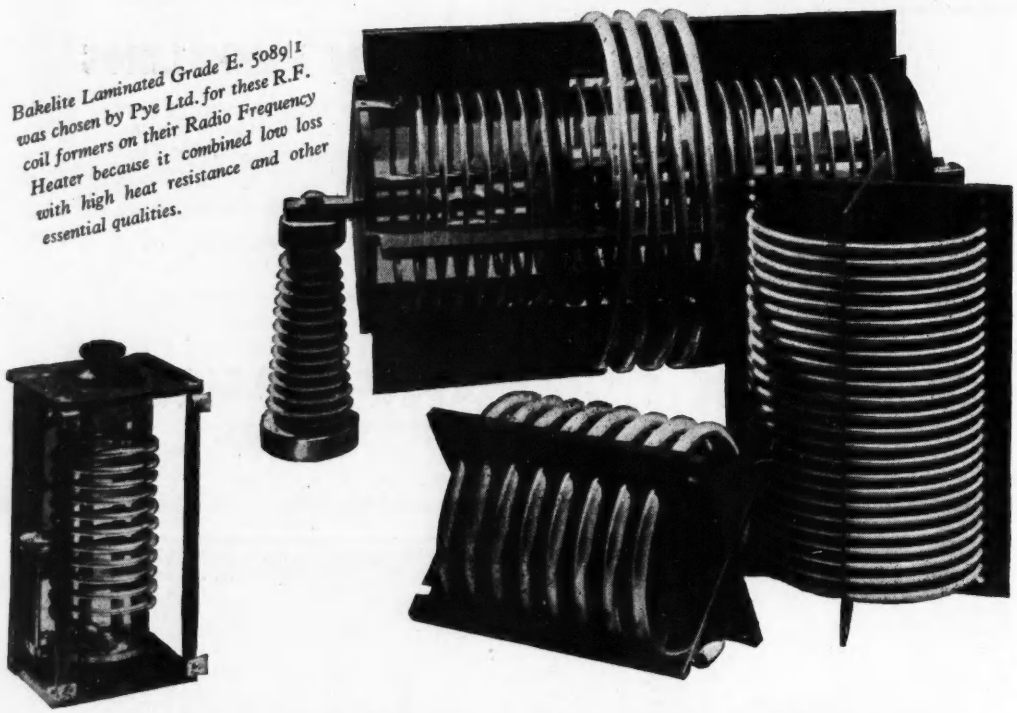

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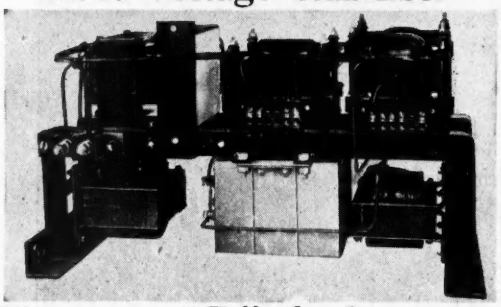

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Electronic Engineering

JUNE, 1947

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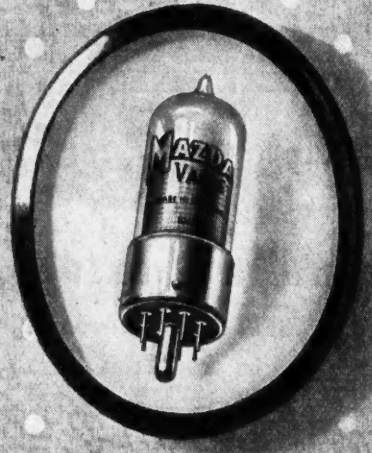

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Experimental Science

UNDER this title the Institute of Physics have just issued an attractive booklet which outlines the proposed scheme of National Certificates in Applied Physics. The key to the scheme can be found in the introductory words: "Nearly every research department in industry and in Government establishments employs fully qualified professional physicists and each professional physicist needs two or three assistants who will require a knowledge of the fundamentals of physics and some skill in experimental technique. . . . Not only is there a very satisfactory career for a boy or girl here, but the brighter ones may proceed to full professional status without the necessity of a University degree."

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This is the only part of the booklet which invites comment. In these days of inflated values there are many youths of 18 who are pulling in more than £3 a week, and they prefer to have substance rather than status. But this can easily be adjusted by the employer requiring the Certificate as a condition of employment, and any boy who really wants to make his way in scientific work would be willing to forego a little money at the start.

This scheme is not intended as a short cut to qualification by students who are attracted to some branches of research and who think that a smattering of physics will serve their purpose. No one will go far who is not well grounded in the fundamentals, and this proposal of the Institute will certainly help those who cannot go in for a full academic career.

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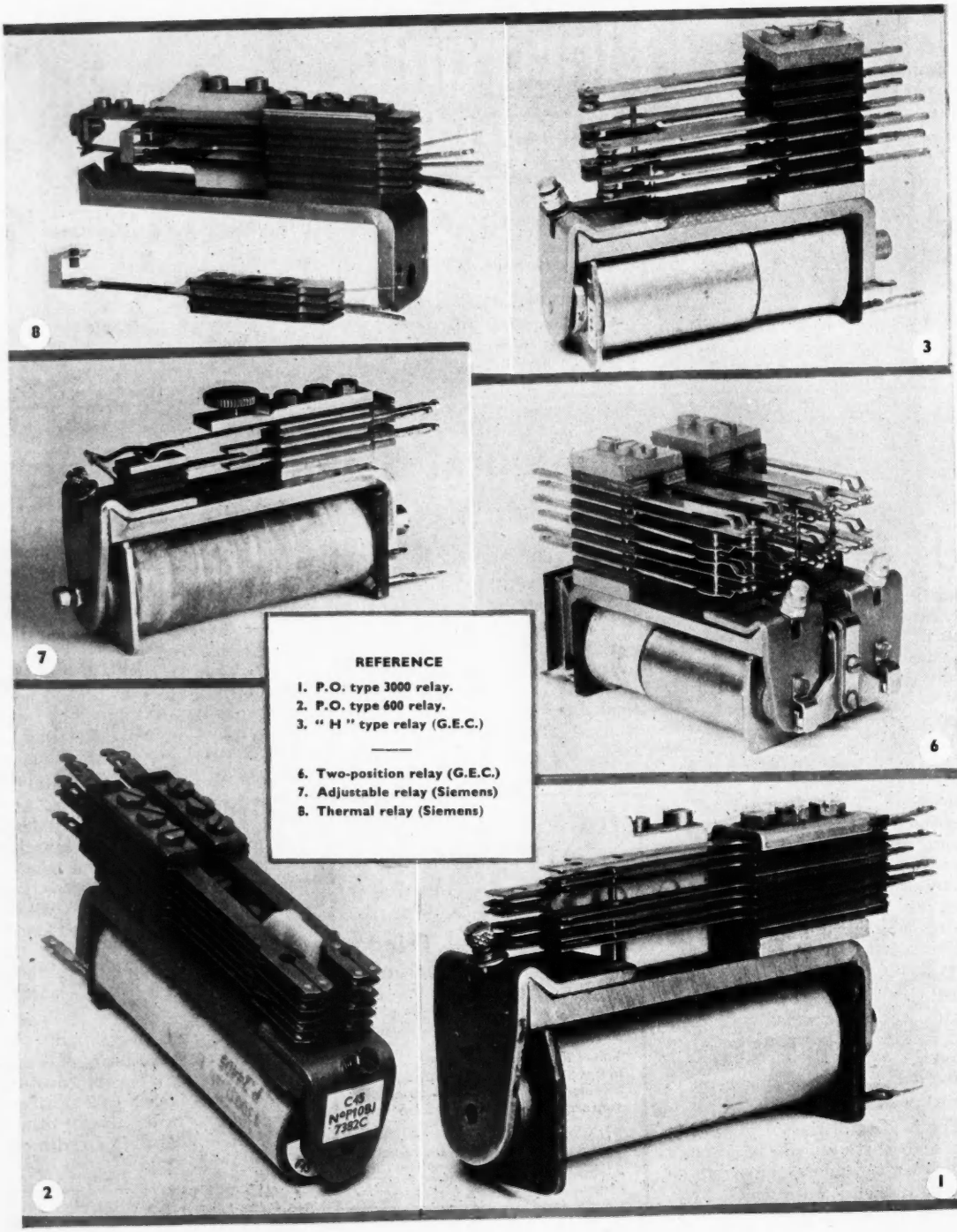
Telephone Relays —



REFERENCE

1. P.O. type 3000 relay.
2. P.O. type 600 relay.
3. " H " type relay (G.E.C.)

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6. Two-position relay (G.E.C.)
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* The

and their use in Electronic Circuits

By A. A. CHUBB, A.M.I.E.E.*

WITH the increasing use of electronic control gear in industry, there is a growing tendency to follow electronic apparatus such as photo-cells, sensitive amplifiers, and the like, with control circuits of some complexity, needing relays of predictable characteristics and long working life. Relays of this kind have been known in the telephone industry for many years where they are used in conjunction with step-by-step or rotary switches to effect connexions between one subscriber and another with a degree of certainty which is actually much higher than is supposed to be thought by the subscriber. These relays are eminently suitable for incorporation in valve circuits, both as links between these circuits and subsequent control apparatus and also to bring sections of valve gear into or out of use, or to modify its action. The aim of this article is both to describe certain standard forms of telephone type relays and explain their characteristics and also to show how such relays can be employed to fulfil some commonly occurring requirements in the electronic field.

P.O. 3000 Relay

Possibly the best known form of relay is that shown in Fig. 1. This is the "major" or P.O. 3000 type. It consists of a yoke having a knife edge at one end on which an armature pivots, the armature being held in position by a spring-loaded washer on the armature retaining screw. The magnetic circuit is completed by the core of the operating coil, all the magnetic materials having as low a retentivity as possible. Since the magnetic circuit is not laminated, it is not suitable for operation by alternating current, though a relay can be used as an impedance in a circuit carrying currents of speech frequency. In such a situation its impedance to 800 c/s. is roughly ten times its D.C. ohmic resistance.

The armature movement or travel is limited in an unoperated position by a stud which co-operates with the yoke, and in an operated position by a fixed residual or adjustable residual screw which prevents the armature from touching the pole face. This ensures that an airgap of not less than 0.004 in. always exists in the magnetic circuit, and the demagnetising effect of this gap provides a reliable release on disconnexion of the operating current.

The function of the relay is to open or close contacts when the armature is moved. The contacts are of four kinds; make, break, change-over and make-before-break, abbreviated as 'm,' 'b,' 'c' and 'k' respectively. Almost any combination of contacts from one make to six change-overs can be carried by one major relay, the contact springs being arranged on each side of a central stepped insulating block on which some of them rest when the relay armature is in either extreme position. An upper limit of 18 springs is set by the construction of the relay.

Contacts

To ensure a low-resistance path between contact springs each of the latter is tipped with two contact points, and the springs are given a "set" or pressure by bending during manufacture, so that on a normal relay, made contacts have a pressure of 16-20 grams between them. The contact points themselves are of pure silver for currents up to 0.3 ampere, and of platinum for currents beyond this value, up to 1 ampere, in circuits not exceeding 100 volts. Platinum is also employed for extremely long life when carrying smaller currents than 0.3 ampere. The doubling of the contact points, which are mounted on the split ends of the springs, decreases the high resistance fault incidence due to dirt, by about 11 times as compared with single-ended contact springs.

Faults due to the accretion of dirt on contacts are most likely to interfere with the operation of relay circuits. The effects of such dirt are kept at a minimum by the features of design mentioned above, and also by the circuit conditions of use. If silver is employed, the contacts should carry a current of at least a few milliamperes when closed, and break this current on operation so that the slight resulting spark blows any particles of dirt away from the contacts. In addition, although silver does tarnish in industrial atmospheres containing sulphur, the resulting coating of silver sulphide formed is not only a partial conductor but is of a soft and flaky nature and is easily displaced during use.

While platinum does not form a non-conducting oxide or sulphide on its surface during operation, it is much more expensive than silver and hence its use is confined to circuits carrying appreciable currents or having components of high inductance. In the latter case, *e.g.*, if the contact is operating a step-by-step switch magnet, it is advisable to fit a spark quench device consisting of a 1 μF capacitor, in series with a 100-ohm non-inductive resistance, this combination being connected in parallel with the magnet coil. This greatly reduces sparking, and prolongs the life of the contact.

As regards insulation, the major relay of standard finish has a 500 V A.C. test applied between springs and yoke and between coil and core. Certain forms of springset are also available which are designed to withstand 1,000 V A.C. test pressure. From I.E.E. regulations it will be seen that standard springsets are devised for incorporation in circuits working on a 50 V supply (the maximum normally used in telephone exchanges), and the special springsets enable mains potentials up to 250 V to be switched. Higher potentials can be dealt with by a different form of relay to be described later.

Sensitivity

Major type relays are the most sensitive of the multi-contact type of telephone relay. Table 1 overleaf shows sensitivity figures for a relay of this type fitted with the contact spring combinations shown. The figures are given in terms of power so that the current necessary to operate a given springset combination can be derived from the coil resistance.

It will be seen that the operating power of a relay does not exactly correspond with the relation $w = kn$, where k is a constant and n is the

* The General Electric Co. Ltd., Coventry Works.

number of springsets. Nor is it possible to add the powers for several springsets arithmetically to arrive at an exact operating figure for the combination. However, it is possible to make interpolations from the table which give an approximate value for any required relay.

The points of design which prevent the actual relay from following an exact operating (power/no. of springs) law are that friction occurs at the point at which the armature lifts the spring operating stud, and at the point where one operating stud operates the spring next above it; in addition, since the contacts in operating move in approximate arcs which are centred at different points, friction and sliding also occurs at the junctions of the contact points themselves. These frictions oppose operation of the relay, though their effect is not very noticeable compared with the power required to bend the contact springs. Lastly, test acceptance tolerances have to be such as to cover all the relays of one type which are correctly made, though mechanical tolerances may cause considerable variation in electrical performance between similar relays of a batch.

P.O. 600 " Minor " Relay.

The " minor " or P.600 type relay (Fig. 2) is a smaller version of the multi-contact relay. Whereas the major relay is 4 in. long, 2 1/16 in. high, and mounts on 1 3/16 in. centres, the minor relay is 3½ in. long, 1½ in. high and mounts on ⅞ in. centres. As the copper space on the coil and the cross-section of the iron of the core are both smaller, the sensitivity of the minor relay is approximately 40 per cent. lower than the equivalent major relay. In addition, it is limited to six springs on each side of the central block, and as its manufacturing tolerances have more influence on its operation because of its reduced size, the variation in operating figures among similar relays of a batch is greater. It can, however, be readily employed for straightforward switching operations in such apparatus as portable radio sets, and as both it and the major relay are mounted by screws at the end of the yoke, they can be incorporated on a chassis among valve apparatus where mounting space is limited. The mounting position is preferably such as to make the planes of the contact springs vertical. This enables dust to drop clear of the contacts.

TABLE 1

Operating power for 3000 type relay, milliwatts.

Springset Combination	Residual		
	4 mils	12 mils	20 mils
1 m	—	22	36
2 m	30	43	64
3 m	43	64	100
4 m	56	81	144
6 m	81	144	225
1 c	—	36	49
2 c	43	72	100
4 c	90	144	196
1 b	—	36	49
2 b	43	64	90
4 b	81	144	196
1 k	—	25	43
2 k	31	49	81
4 k	64	100	169

Note:— Coil resistance can be 0.3-20,000 ohms.

TABLE 2

Preferred coil resistances, ohms.

Major Relay		Minor Relay	
Single Winding	Two Windings 50/50	Single Winding	Two Windings
1		1	
100 (6v)	200/200	50 (6v)	100/100
200 (12v)			
500	500/500	200 (12v)	500/500
1,000 (24v)			
2,000 (50v)	2,000/2,000	600 (24v)	
6,500		1,700 (50v)	
20,000		4,000	

Like the major relay, the minor relay has double silver or platinum contacts, and can be fitted with operating coils having a range of resistances from 0.3 ohms to 7,800 ohms. Operating coils are fitted with two or four connecting tags, and the core may therefore carry any combination of coils which can be connected to four tags, though a standard range of recommended resistances is as shown in Table 2.

The figures given in brackets indicate the operating voltage required for moderate or light spring loadings. The foregoing two relays are all manufactured to the same specifications by all the large manufacturers of telephone apparatus in this country. If higher voltages are to be switched than can be catered for by the P.3000 or P.600 type relays, the one shown in Fig. 3 manufactured by the General Electric Co., Ltd., is available. This relay, referred to as the H type, while having a magnetic circuit similar to the 3000 type relay, has a springset having higher insulation which is given a 4,000 V A.C. test to frame, and between adjacent springs. It is therefore suitable for making and breaking circuits having potentials up to 2,000 volts, though if any appreciable amount of current is broken while passing through a high inductance from such a high voltage source, spark quenching circuits must be used to prevent contact burning.

Since the travel of the armature of the H relay is longer than the P.3000 type its sensitivity is about 30 per cent. less for an equivalent springset. Again, although mounting on the same fixing centres its overall height is greater in view of the greater thickness of insulation between the separate springs.

Micro-gap Relay

For special applications a type similar to that shown in Fig. 4 has been used. This is a P.3000 type relay, but the springs are of phosphor bronze instead of german silver to increase the conductivity, and the contacts employed are of silver or silver nickel sintered alloy, and are separated by only 0.005 in. when open. This relay is used for switching A.C. up to 5 amperes at 250 V, the microgap principle being employed. This principle was described by Dr. Thornton in 1934; according to its teaching, a contact for A.C. should make and break comparatively slowly, the contact opening being only sufficient to prevent flash-over in air, or accidental short-circuiting by metallic dust. The relay shown has two such contacts, and is preferably used with a copper " slug " coil to decrease the speed of operation and release. One such relay, tested by the writer, performed 100,000 openings and closures of a transformer primary circuit, loaded to 1 KW at 230 V, without failure.

Relay for V.H.F.

Fig. 5 shows a relay of a type of interest to radio engineers working in the 30-300 Mc/s. field. This relay has a change-over V.H.F. contact with auxiliary low-frequency contacts and is of the P.600 type. Its peculiarity lies in that the characteristic impedance of the V.H.F. change-over springset is made equal to a 70-ohm transmission line by the use of flat earth-connected springs located between and beyond the three conductor springs, these earthed springs being provided with contacts such that the outer spring of the change-over with which the centre spring is not at any given time in contact, is earthed. The spacing between the current-carrying and earthed springs is made so as to give the characteristic impedance mentioned above, and V.H.F. loss is kept small by the use of ceramic insulators. The relay can

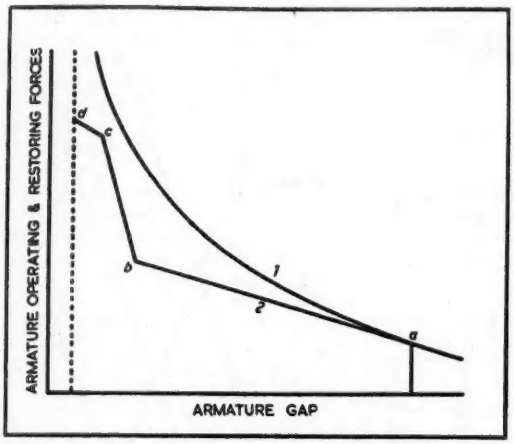

Fig. 9. Characteristics of relay (m and k).

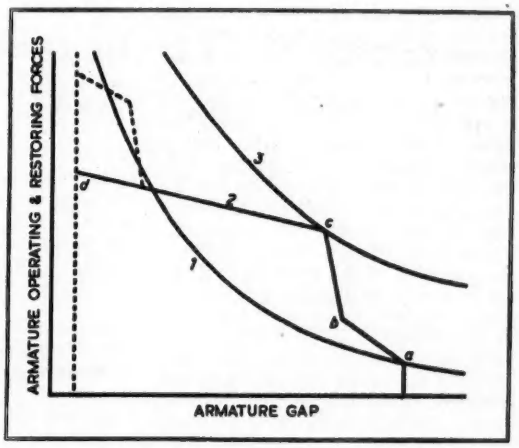

Fig. 10. Characteristics of relay (c and b).

carry up to 20 watts at 100 Mc/s., and other forms of relay are available to carry up to 1 KW in the same frequency band.

Fig. 6 shows a relay for use where maximum economy of current is essential. It is a two-position device, consisting of two P.3000 or H type relays with interlocked armatures, the interlocking arm being spring-biassed so as to remain only in either of its two extreme positions of travel. Momentary application of current to one operating coil operates one armature and releases the other, while momentary application of current to the other coil reverses the process. Both relays can carry their full complement of contact springs, and neither coil need remain energised once armature movement has ceased.

Fig. 7 shows a relay for use primarily in the anode circuits of valves made by Siemens Bros., Ltd. In valve circuits it is often necessary either to have a relay which has a close 'operate/release' current ratio, or which operates or releases completely once armature movement has begun. For reasons to be stated later these conditions are not easy to fulfil. The relay shown, however, which is of the P.3000 type, has an operate/release ratio of 2:1, and its operate figure can be altered to a certain degree by the screw shown. The replacement of a broken valve, even if accompanied by a change in steady anode current, can thus be compensated for by the screw. The relay is suitable for following morse characters, for operating or releasing when a slowly rising or falling anode current reaches a particular value, for preventing anode overloads, and the like. The contacts handle 1 ampere at 50 V D.C., and one or two change-over springsets can be carried by one relay.

When switching on valve circuits employing mercury vapour rectifiers, it is essential to ensure that a delay of 30-40 seconds is allowed between the application of current to the rectifier filaments and supply of H.T. to the valves. This delay may be provided by the Siemens thermal relay shown in Fig. 8. This is a compensated bimetal combination having one bimetal strip wound with resistance wire and provided with a change-over contact, the whole being mounted on a telephone-type relay yoke. If required, an operating coil, armature and contacts may be added to make a thermal delay relay combination. This device may be employed for H.T. switching as mentioned above, the bimetal strip being first heated to close the switching contacts, then disconnected and allowed to cool. This procedure ensures that if the valves are switched off soon after switching on H.T., the full delay of the bimetal strip is provided before H.T. can be re-switched. Full particulars of the use of this relay may be obtained from the manufacturers.

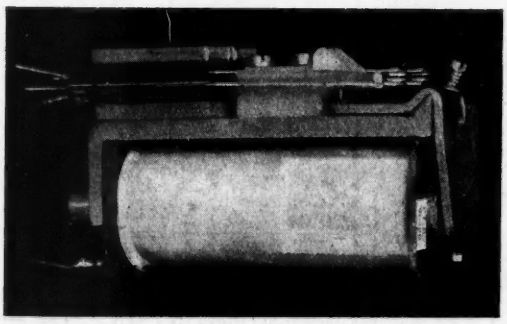

Fig. 4. Micro-gap relay for switching A.C.

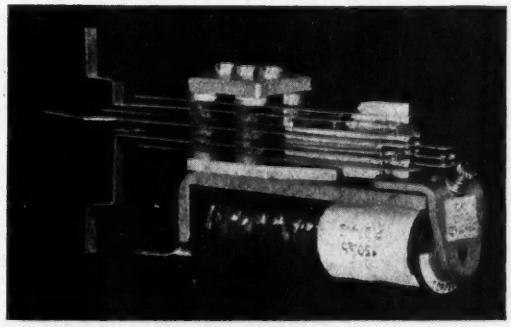

Fig. 5. Relay for V.H.F. working.

Certain points in connexion with the operation characteristics of relays are worth notice. Electronic engineers often require a relay to operate or release positively, that is, completely, without an intermediate pause, with an anode current that is slowly increasing or decreasing. This can only be accomplished by a relay carrying a small number of " make " contacts and of moderate sensitivity. Referring to Fig. 9, curve (1) shows the variation of the magnetic pull on the armature of a relay subject to a steady current in its operating coil, as the armature is allowed to move from its position of rest and approach the pole face until stopped at a fixed distance therefrom by its residual stud. The pull is of the order

$$p = \frac{k}{(a+d)^2}$$

where k is a constant depending on the magnetic circuit construction, a is a constant determined by the form of the knife edge and the fit of the heel end of the core in the yoke, and d is the mean instantaneous distance of the armature from the pole face. The figure a is small compared with d until the armature approaches closely to the pole face. The curve can therefore be assumed for practical purposes to be hyperbolic. A family of such curves can be drawn for various values of coil current.

Curve (2) shows the variation of force exerted on the armature, by the contact springs of a relay having a single m or k contact, the bottom spring of which is tensioned down on to the relay armature, measured at the mean point of application of the operating field. At the point (a) the magnetic field just overcomes the restoring force acting on the armature due to the contact spring and the armature starts to move, closing the gap between itself and the pole face. The restoring force of the bending contact spring increases linearly with armature movement until point (b) is reached, when the contacts close and the pressure of the top spring is taken up to point (c), when the spring leaves the insulating block of the relay on which it had been tensioned. Thereafter both springs bend together till point (d) is reached, when the residual stud reaches the pole face and armature movement ceases. Throughout this operation the magnetic pull curve lies above the restoring force curve, so that once armature movement has started it continues until the stroke is completed.

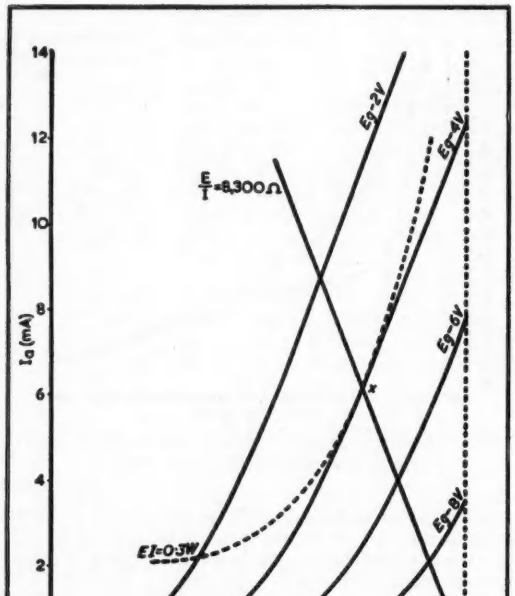

Fig. 11. Matching of relay to valve.

If, however, a b or c contact is employed, conditions are as shown in Fig. 10. In this figure, curve 2 is the restoring force of the contact springs. As current rises in the coil, curve 1 point (a) is reached, where the magnetic pull just equals the spring restoring force. The two breaking contacts now move together, the current rising meanwhile, till point (b) is reached when the bottom spring of the break encounters a stop. Further increase of current to curve (3) is now necessary to move the top contact from the bottom and complete the break action, the armature " floating " part-way operated while the current is between the values (1) and (3). The dotted portion attached to curve (2) shows the effect of the third or make spring in a change-over action. It can thus be seen that complete or " flip over " action of a relay can only take place on a slowly varying current if the relay carries m or k springsets of the normal type. Even so, owing to the increasing frictional component introduced by operating pins and bushes in a multi-spring combination, a large assembly of make springs does not give such a good characteristic as a small number.

Any major, minor, high voltage or mains relay may be provided with a copper " slug " on the front or heel end of the relay coil. This slug reduces the sensitivity of the relay by occupying winding space, but it enables the relay to be slow releasing for a heel-end slug, or slow operating and releasing for a front end slug. The degree of retardation is not large. Thus, if a major relay takes 20 m.sec. to operate or release with a plain fully wound coil, it may take 60-80 m.sec. to operate with a front end slug, and 200-300 m.sec. to release with a front or heel end slug. Times much in excess of these are not reliably obtainable. The sensitivity of the relay is reduced to about 0.6 of its fully wound figure for a 1 in. slug.

To obtain the best output of relay operating power from a valve operating under given conditions, it is essential to derive an impedance match as shown in Fig. 11. It is obvious that for a given valve, H.T. and bias voltages, the higher the value of relay resistance inserted in the anode circuit the less the anode current. Conversely if the relay resistance is lowered its sensitivity is correspondingly reduced. The best value is obtained by drawing a set of

$E_a - I_a$ curves for the valve used, and selecting the line of the bias voltage at which the relay is to operate. A set of curves of the form: Watts = EI for several values of watts are now drawn with the ordinate E_a = maximum anode voltage for one asymptote and the abscissa $I_a = 0$ as the other, and with the origin at their point of intersection. These curves are hyperbolas, and the one which touches, or nearly touches, the grid voltage curve gives the best resistance for the relay from the relation $R = E/I$, the values E and I being taken from the juncture of the two curves. In the figure a valve type L63 is used, with a maximum anode voltage of 200 and an operating grid potential of -4 V. The dotted power curve $EI = 0.3$ watt is seen to be asymptotic to the $E_g - 4$ V curve at the point X. The slope of the line joining this point to the point $E_a = 200$, $I_a = 0$ gives the resistance of the relay, which should be 8,300 ohms. As, however, the shapes of the valve characteristics and relay wattage curves are somewhat alike at the correct operating point, it will be found that considerable variations in relay resistance result in relatively little variation in maximum power developed in the relay, so that relay to valve matching is not critical for a triode. Pentodes can also be matched by this method, but here the matching must be more accurate for best results.

A further use for the curves is that of deducing the minimum grid voltage at which a relay will operate. If a power curve is drawn to the same asymptotes as previously, the power being that necessary to operate a required springset, and an anode voltage-anode current curve drawn to touch the hyperbola, then the grid voltage corresponding to this curve is that at which the relay just operates and the load line at the point of tangency gives the relay resistance required. The change in grid voltage from the steady bias or non-operate condition to the tangent curve is the minimum which can be used for the particular valve under the operating conditions chosen. A similar procedure can be employed to find the minimum grid voltage to release a given relay if the release power of the relay is known. This may be from 1/10th to 1/50th the operating power, depending on the relay residual, number of springsets and spring pressures.

(To be continued)

Measurement of H.T. by Cathode-Ray Tube

IN the normal operation of a cathode-ray tube, for example in a television receiver, the electron beam is subjected to fields which produce a constriction or cross-over close-up to the cathode, and again at the fluorescent screen. It is, however, possible to produce a further cross-over at an intermediate point along the beam, and, in particular, where the focusing system is an electrostatic lens produced by the juxtaposition of two axially consecutive tabular anodes, such an intermediate cross-over will be formed if the ratio of second to first anode potential (*i.e.*, the focusing ratio) is made sufficiently high, having regard to the tube geometry.[1]

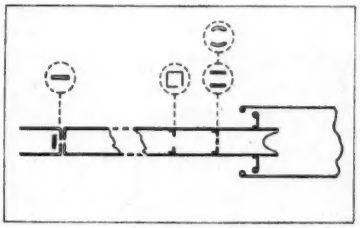

Fig. 1.

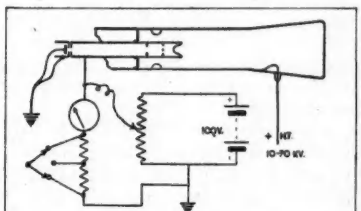

Fig. 2

This property can be used to effect accurate measurement of high voltages, in the following way. A cathode-ray tube is employed having a known focusing ratio, and the unknown high voltage is applied to its second anode. An adjustable and comparatively low voltage applied to the first anode is measured by an ordinary moving coil instrument, and this may if desired be calibrated to give directly the value of the applied H.T. corresponding to accurate focusing of the beam on the fluorescent screen.

In order to facilitate the observation of the screen, a tube of special construction is used. This tube has a cathode shield with an elongated slot aperture instead of the more usual circular aperture, and the end of the first anode facing the cathode shield has a similar slot, the two being aligned. This gives rise to a beam of rectangular section, or "ribbon" beam, in place of the more usual "pencil"; and by interposing further along this tubular first anode a diaphragm having two slot apertures with their lengths parallel to the width of the ribbon, a thick medial "slice" of the beam is constructed while two equally offset thin "slices" are afforded passage. The focusing field set up between first and second anodes has the effect of converging these two "slices" so that, with the high voltage ratio employed, they cross over first within the lens field and again in the region of the fluorescent screen, where the superposition of the two fluorescing lines indicates accurate focusing. The screen end of the first anode penetrates some distance into the second anode, and is finished off with a pair of "lips," this construction having been found to enable a wide ribbon beam to be focused as a straight line on the screen.[2]

The diagrams illustrate the tube gun (Fig. 1) and the general arrangement and circuit (Fig. 2). The high voltage anode is shown as a wall coating, its edge adjacent the low voltage anode being polished and rounded to avoid sparking.

If it is desirable to distinguish rapidly whether a given non-focused indication on the screen corresponds to the over-focused or the under-focused condition, the two slots in the double-apertured diaphragm may be curved slightly (as illustrated above the parallel slot arrangement).

Communication from E.M.I. Laboratories

[1] See, for example, British Patent No. 495,707—Nicoll.

[2] This is one of a number of constructions for line focusing in Cathode ray tubes described in detail in British Patent No. 574,056—Klemperer.

Electrical Analogue Computing—*Part I.*

By D. J. MYNALL, B.Sc., A.M.I.E.E.*

A broad survey of the basic operations of electro-mechanical and electronic analogue computing, and an indication of the trend of development.

IN a study of the means for carrying out mathematical computations automatically, it is essential to be clear as to the distinction between the analogue and the digital principles

This article sets out to describe characteristic methods employed in electrical analogue computing, to indicate the direction in which development is likely to tend (in an attempt to realise the potentialities offered by the full exploitation of electronics), and to show the nature of the particular spheres of usefulness of this type of apparatus.

Employment of the analogue principle results in apparatus in which chosen physical quantities vary in a manner mathematically analogous to the variation of the numbers in the problem under consideration. In any particular piece of apparatus, there exists, of course, an accuracy limit beyond which it is not possible to set up the input quantities or to read the result.

On the other hand, digital computing apparatus works out problems by methods which are basically the same as those which would be employed if an attempt were made to perform the calculations on paper. The elements in such apparatus have purely positional significance, after the fashion of beads on a counting-frame, and there is thus no fundamental limit to the accuracy obtainable.

It would appear, at first sight, therefore, that digital methods are to be preferred. However, in general, the analogue principle gives apparatus which is smaller and lighter than the equivalent digital apparatus, and it thus has fields of application in which it is particularly advantageous. The two principles are complementary rather than competitive.

Great advances have been made recently in digital computing, due to the application of pure electronic technique.[1,2] The writer is of the opinion that a similar type of advance will eventually be established in analogue computing, though on a less spectacular scale and with a different sphere of usefulness. A return is made to this point after the possibilities of pure electronic analogue computing have been indicated.

The mathematical processes dealt with in this article are the basic operations such as addition, multiplication, differentiation, integration, and a few others which do not come directly under these heads.

The examples which are given later have been chosen for the generality of their application and for their usefulness in demonstrating principles.

The art is extensive, so that, of necessity, some interesting examples of technique have been omitted or given but brief mention. It is hoped that the references quoted will in some measure compensate for this.

The accuracy of performance of each individual example is not discussed, but, as a general guide, it may be taken that the magnitude of error which it is reasonable to tolerate (at the present state of the technique) is between one per cent. and one-tenth of one per cent. The higher tolerances relate to complete systems and the lower to individual units. Throughout the article the word "unit" is reserved for a part of the circuit performing some definite and relatively simple function, such as adding together several quantities or multiplying one quantity into another. A unit is composed of "elements" such as resistors, thermionic valves, electric motors and the like.

Electro-Mechanical and Electronic Systems

It is convenient to divide units into one or other of two groups, according as they do or do not contain active mechanical elements. The units from which active mechanical elements are excluded will be called "electronic," and the other units (which, incidentally, may include electronic elements) will be called "electro-mechanical."

In the same way, systems containing electronic units only will be called "electronic," and all other systems will be called "electro-mechanical." The significance of this distinction will be made clearer later.

Basic Quantities

In computing systems of some complexity it is good practice to express the input data consistently in terms of one basic quantity, such as voltage or current, and to carry out the stages of the calculations in such a fashion that each unit accepts and delivers this basic quantity.

The observance of this general principle rationalises the design of elaborate systems, and gives the maximum flexibility to systems which must allow of changes of layout to suit different problems.

In electro-mechanical systems it may be considered good practice to have two basic quantities, one mechanical and the other electrical, provided that the mechanical quantity is used consistently to represent one type of data, while the electrical quantity is used consistently to represent another type. For example, voltage might be used to represent the parts or the modulus of a complex number, while mechanical shaft rotation might represent the angle of the same number.

Algebraic Addition

To move from the general to the particular, the operation of algebraic addition may be considered first, since it is obviously a prime requirement, and is one which linear electrical circuits are well adapted to deal with, by a variety of methods.

For example, alternating voltage amplitude may be chosen as the analogue quantity and the desired sum reached by series connexion of the secondary windings of a number of unity-ratio transformers as shown in Fig. 1. Provided that the voltage wave-forms are all alike in shape and relative timing they need not be sinusoidal. A completely inverted

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wave-form will, of course, represent a negative number, and the system covers the algebraic addition of real numbers. Inversion of a transformer connexion may be used to reverse the sign of a number, as shown in Fig. 2.

The same arrangement deals correctly with the addition of complex numbers if it is arranged to represent the modulus of a number by the magnitude of a sinusoidal voltage, and the angle of the number by the phase angle relative to a chosen datum. The in-phase components of the input voltages add algebraically to give the in-phase component of the output voltage and represent the addition of the real parts of the complex numbers to give the real part of the resultant sum. Similarly, the quadrature components of the voltages represent the imaginary parts of the complex numbers and the quadrature component of the output voltage gives the imaginary part of the sum. This follows immediately from the well-known one-to-one correspondence between the vector diagram for the addition of the voltages and the Argand diagram for the complex numbers.

Variation of the transformer turns ratios from unity allows a general extension to linear functions of the input variables,[3] as shown in Fig. 3.

Another important method of adding voltages may be called "star mixing". It is particularly well suited to electronic systems, and is able to deal with a wide frequency range, from D.C. upwards.

Suppose, for example, that it is desired to sum the voltages from n sources by this method. It is sufficient to join n equal admittances in a star-point and to connect each of the free ends of the star to one of the sources to obtain a voltage at the star-point which is $1/n$ th of the desired sum.

The star admittances are generally (and for D.C., necessarily) conductances.

Precisely the same remarks with regard to alternating voltages apply as before, and general types of linear functions may be set up by making the star admittances unequal.

Loading from the star-point to "earth" alters the detail design but not the principle, and may readily be taken into account.

Fig. 4 is an illustration of the most general form of star mixing when $n = 3$. It is useful to work in terms of admittance rather than impedance, as

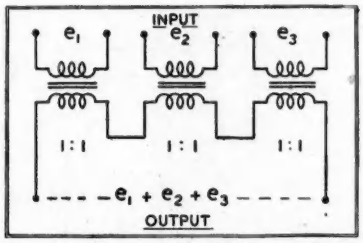

Fig. 1. Algebraic addition by the use of unity ratio transformers : positive quantities.

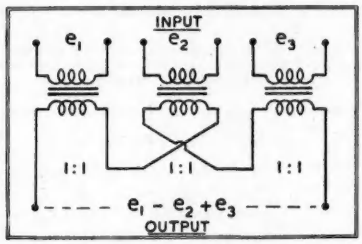

Fig. 2. The reversal of a winding changes the sign of a quantity.

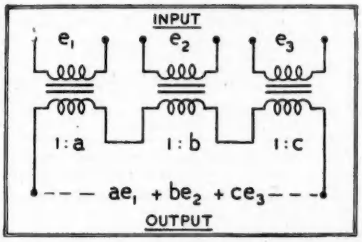

Fig. 3. Varying the ratios of the transformer windings gives a linear function of the input variables.

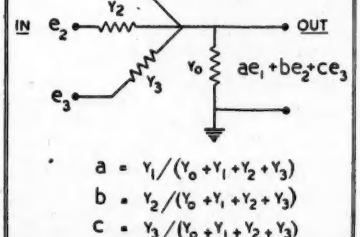

Fig. 4. Star mixing. Another method of forming a linear function of the input variables.

the expressions for the weighting coefficients in the output function assume a simpler mathematical form, which makes it clear that in order to adjust one of the coefficients, without affecting the others, an equal and opposite variation should be imposed on the associated star admittance and the loading admittance.

Apart from their use in more elaborate systems, these principles suffice in themselves to form the basis for simultaneous linear equation solvers. This subject may be followed up for example in Reference 4, which deals with a commercial application of the star mixing method and the general theory of the classical iterative method of using such apparatus.

So far, in the consideration of addition, electronics has not appeared specifically, though it will be understood that circuits such as Figs. 3 and 4 may well employ electronic excitation and indication.

In particular, an electronic amplifier is well adapted to restore the loss of level which is sustained in every star mixing process.

The Thermionic Valve as a Computing Circuit Element

Before going further, it will be as well to consider some general properties of a vital element in electronic computing systems — the thermionic valve.

The thermionic valve has the advantage that it can operate at speeds far in excess of any mechanical device. It also offers the features of readily providing power gain from point to point of the circuit and of acting as a more-or-less unidirectional buffer, thus simplifying interaction problems when compounding units to form a complete system

But for these advantages the valve would not find a place in precision systems, because it also offers the disadvantage that one cannot rely upon its characteristics remaining unchanged during warming-up, under changes of ambient temperature, or with normal ageing. Nor is there likely to be close similarity of characteristics between valves of one and the same type. This means that the direct use of the valve characteristic is ruled out.

Fortunately, various artifices are available to make the overall performance of valve circuits depend almost entirely on circuit elements which are more uniform and consistent in performance. The principle involved, which is known as "negative feedback", was first explicitly investigated and used on an extensive scale in connexion with communication networks[5,6] and the technique was thus ready for application to computing circuits. This principle

is so important that a simple but characteristic application will be described before proceeding with the description of units for performing other mathematical operations.

Negative Feedback

In Fig. 5, the block represents a high-gain, direct-coupled, voltage amplifier. The numerical value of the gain, A, is an "instantaneous" value which is not necessarily known with any exactitude: it will vary due to factors which have already been enumerated and will also be a function of the input voltage, owing to non-linearity of the valve characteristics. For simplicity, it is assumed that the input resistance of the amplifier is infinite, the output resistance zero, and that zero output voltage corresponds to zero input voltage. Departure from these conditions can readily be taken into account, but would merely obscure the main point. A resistor, R, connected between the input and output terminals, provides the feedback link.

With these assumptions, it is easy to show that the input resistance and the transresistance of the whole circuit have the values given on the diagram. These are instantaneous values, which will vary as A varies. The transresistance has the dimensions of resistance since it is defined as the ratio of the output voltage to the input current.

The important point to note is that the transresistance approaches a limit $-R$, as the value of A is raised, and that this limit is independent of A. Thus, provided A be sufficiently great, large variations in A result in negligible variations in the transresistance. In other words, this property of the circuit has been made to depend on the characteristics of a resistor rather than on the characteristics of the valve or valves, which are merely the means for obtaining a high value of A.

Furthermore, the input resistance, though directly subject to the variations of A, approaches zero as the value of A is raised, and can be made extremely small.

It is a short step to the amplifier of Fig. 6, which has been formed by the addition of a resistor, r, on the input side. The input resistance and voltage gain are as shown on the diagram, and both approach independence of A as A is raised in value.

An amplifier of this type is commonly used for addition by star mixing, the resistor r being replaced by

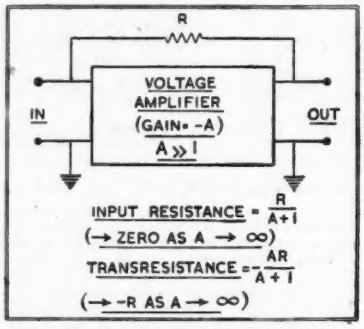

Fig. 5. The application of negative feedback to a valve amplifier, showing effect of R on the input resistance and transresistance.

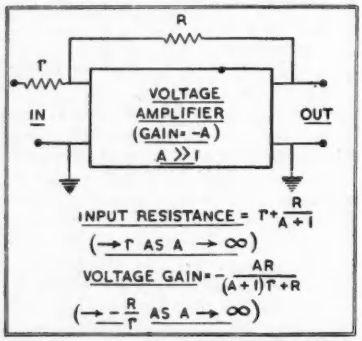

Fig. 6. Addition of input resistance r to Fig. 5 to form feedback amplifier.

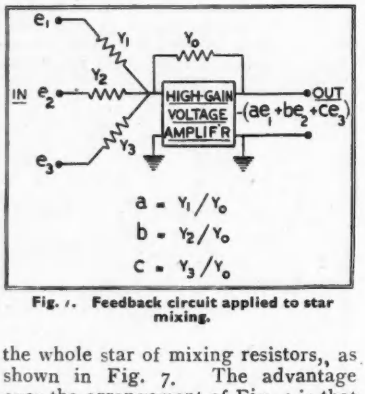

Fig. 7. Feedback circuit applied to star mixing.

the whole star of mixing resistors,, as shown in Fig. 7. The advantage over the arrangement of Fig. 4 is that adjustment of the star admittance associated with one of the input variables affects only the associated constant in the output function (no compensating adjustment elsewhere being called for) and the output level is independently adjustable by variation of the feedback admittance. Where the change of sign is significant it can be corrected by a unity-gain amplifier of the same general type.

It may be noted, in passing, that when direct voltage is being handled by such a system the stability of the zero is not ensured by the means described. One way of overcoming this difficulty is to convert the input to A.C., by high-speed mechanical interruption or some form of modulation process, reverting to D.C. at the output terminals by means of synchronous demodulation at high level. This technique is an art in itself, too extensive to be dealt with in detail in this article. A useful explanation of the purpose of chopping the input quantity is contained in Reference 7. Several useful embodiments of the principle have not yet appeared in the literature of the subject.

Another method is to employ an auxiliary circuit which examines the zero setting and corrects it when necessary.[8] This avoids the need for chopping the input to the main amplifier, where it may impose an artificial upper limit on speed of response.

Feedback and input elements are not necessarily resistive, as will be seen in examples of electronic differentiators and integrators which are dealt with later.

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(To be continued.)

New Magnetic Alloy

A magnetic alloy of 35 per cent. cobalt, 64 per cent. iron, and 1 per cent. chromium has been developed by Dr. T. D. Yensen, of Westinghouse Research Laboratories, U.S.A. Termed "Hiperco," this alloy is workable and has the highest saturation point of any known material.

A small cold-rolling mill is at present working, with a capacity of 1,000 lb. per day to meet early needs.

—Westinghouse Press Service.

High Power Television Transmitters

—Some Aspects of their Design

Part 2

By

P. A. T. BEVAN, B.Sc., A.M.I.E.E.*

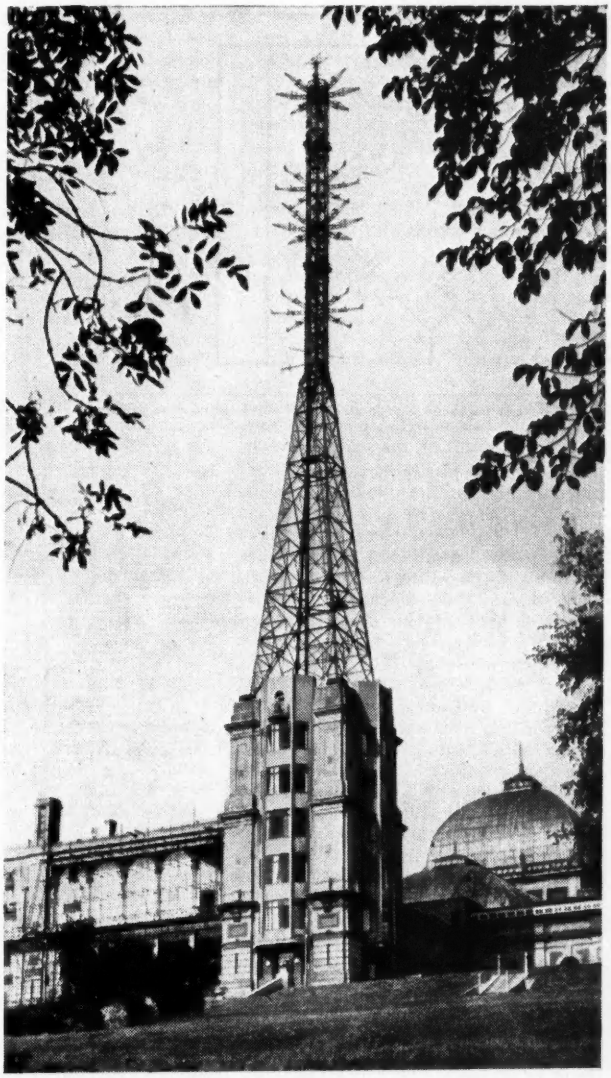


Fig. 10. Vision and sound aerials at Alexandra Palace, connected to the transmitters by copper tube concentric feeders.

SINGLE-SIDED valve circuits unless of the concentric type are in general not suitable for television transmitters of the class described in Part 1 because of their asymmetry with respect to component mounting frames and screening enclosures. The dimensions of these parts become appreciable fractions of the operating wavelength and appear in the circuits as coupled impedances so that a true common R.F. earth balanced with respect to the circuits is difficult to obtain. For these reasons balanced push-pull circuits are usually favoured, particularly for the high-power modulated output stage.

Basically, the push-pull circuit is arranged to form a reactance bridge which should remain balanced over the whole of the carrier and side-band range. Such an arrangement for a neutralised grounded cathode circuit is shown in Fig. 5, where the pair of valves and the pair of anode-to-grid neutralising capacities form the four arms of the bridge. The criterion of balance is that the R.F. output voltage developed across the tank circuit and anodes A_1 A_2 shall produce no voltage across the grid-tuned circuit at B_1 B_2 or on the grids themselves at G_1 G_2.

No feed-back voltage at B_1 B_2 can be achieved by ensuring that the reactances of the four arms (including all strays) are equal, while for no voltage at G_1 and G_2 there must be no reactance between B_1 and G_1 or B_2 and G_2, since a large part of the R.F. anode current flows through the valves from A_1 and A_2 to the grid circuit at B_1 B_2. The condensers C_N are therefore introduced to neutralise the inductance of the grid lead at the carrier frequency. A small voltage will appear on the grids at the higher side-band frequencies which will tend to increase the amplitude of one side-band and reduce the other. For this reason it is important that the inductance of the connexions between the grid circuit and the grids themselves should be reduced to a minimum. In general, in the case of water-cooled valves the disposition of electrodes and connexions of the single-ended type are the most favourable for forming the bridge circuit described.

The condition of operation for a grid modulated push-pull amplifier during modulation by a simplified vision signal, but which embodies the extremes of synchronising pulse, peak white picture and the black level, is illustrated in Fig. 6.

The short intervals of black level which are normally introduced before the start and at the completion of a line of picture signal have been

* Design and Installation Department, the British Broadcasting Corporation.

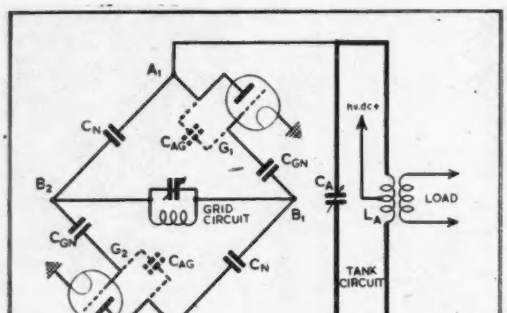
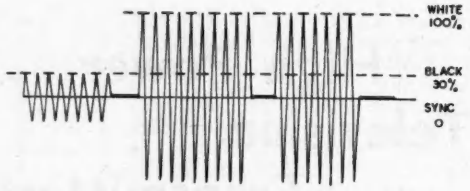


Fig. 5.—Basic balanced bridge circuit for ultra-short-wave wide-band television modulated amplifier.



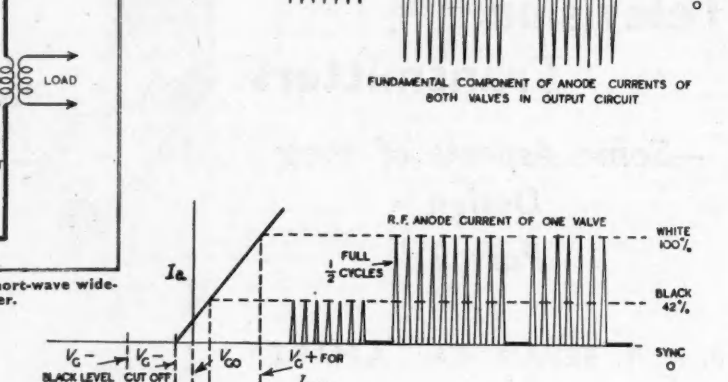

R.F. ANODE CURRENT OF ONE VALVE
WHITE 100%
FULL ½ CYCLES
BLACK 42%
SYNC 0
Ia
Vc− BLACK LEVEL CUT OFF
Vc− FOR
VGO
Vc+ FOR IA MAX. AT VA MIN.
REGION OF POSITIVE GRID VOLTAGE RESULTING IN GRID CURRENT WHICH LOADS THE R.F. DRIVER & MODULATION STAGES
R.F. DRIVING VOLTAGE EG APPLIED TO GRID
MODULATING VISION SIGNAL VOLTAGE EM APPLIED TO GRID
SYNC 0
BLACK 42%
WHITE 100%

Fig. 6. Illustrating the idealised operating conditions of a grid-modulated push-pull R.F. amplifier.

omitted for simplicity while the anode current/grid voltage dynamic characteristic of the valve has been made linear. The best compromise between power output and efficiency is obtained if the valve operates in the Class B condition at peak white. To this end the amplitude of the R.F. driving voltage E_g is made equal to the maximum overall amplitude E_m of the modulating voltage, and the amplitude and positioning of the latter on the grid base of the characteristic is such that on a peak white modulating signal E_g becomes sufficiently positive to generate anode current R.F. pulses of the maximum allowable amplitude and of just 180° duration. At the same time at the trough of a synchronising signal, E_g is such that the anode current is just cut off while a black level signal generates anode current pulses of less than 180° duration and of amplitude sufficient to give a fundamental frequency component of 30 per cent. of the peak white amplitude.

The principal departures from these ideal conditions which occur in practice are:

(a) The non-linearity of the valve anode current/grid voltage characteristic particularly the effect of "bottom bending," which necessitates increasing the relative amplitude of the synchronising pulse to take E_g well below cut-off so as to obtain the desired rectangular output waveform.

(b) The non-linear loading effect of the grid current, taken when grids are driven positive, which results in regulation of the R.F. driving and modulating voltages within this region, and necessitates increasing the open circuit voltage swing of the modulator by an amount equal to the regulation of the drive plus the voltage drop due to the D.C. grid current flowing through the modulator output resistance.

(c) The D.C. voltage regulation of the H.V. supply when transmitting a white picture which results in a fall in the transmitted black level and a departure from ideal Class B operation at peak white.

The combination of these effects necessitates an increase of some 15 per cent. in the overall vision signal output voltage generated by the modulator on open circuit while an amplitude ratio of the peak picture signal to the synchronising pulse approaching unity is necessary to obtain the required transmitted carrier amplitude ratio of 7 : 3.

As previously mentioned if the effect of (b) is swamped in the conventional manner by resistance loading the modulated amplifier grid circuit an R.F. driver stage giving an output of some four times that required to supply the actual grid power loss is needed to maintain the R.F. driving voltage sufficiently constant over the whole of the modulating cycle to achieve a reasonably linear modulation characteristic.

An R.F. cathode follower driver stage was suggested as one method of reducing the regulation of the driving voltage during the grid current region thereby avoiding the use of a swamping resistance load and the attendent waste of driving power.

An alternative method of achieving the same object is to use a conventional driver together with some form of non-linear grid loading device having a characteristic which is approximately the reverse of the grid current characteristic thereby maintaining a constant load on the driver, equal to the peak grid power loss only, over the whole of the modula-

ting cycle. This principle has been used successfully on certain grid modulated Class C sound transmitters, the normal swamping resistance load being replaced by a triode absorber valve, the negative bias on which is increased by the rectified grid current taken by the modulated amplifier so that the proportion of load which the absorber valve imposes on the driver is correspondingly reduced. This scheme has the added advantage that the load impedance presented to the modulator is also maintained constant over the modulating cycle which assists in linearising the regulation of the modulating voltage, an equally necessary factor in obtaining a linear modulation characteristic.

The other main choice offered to the designer is whether to use a straightforward grounded cathode circuit or alternatively a grounded grid or " inverted amplifier " circuit.

Grounded-grid Amplifiers

The grounded grid amplifier is not new but is likely to be widely used for U.S.W. power amplifiers for television and F.M. (*see* Fig. 9). In this circuit the grid instead of the cathode is grounded and is common to both the input and output circuits as shown in Fig. 7, which gives it certain advantages over the grounded cathode circuit for ultra-short-wave wide-band television transmitters. The inter-electrode capacity common to the input and output circuits (and which must be neutralised for stability) is now the anode-to-filament capacity, but with valves of modern construction (*see* Table 1, p. 139) this capacity is usually sufficiently low to permit smaller neutralising capacitor or none at all. It follows that the absence of such capacitors proportionally reduces the total effective anode capacitance, so that the serious limitation which this capacity imposes on the peak power output, useful anode voltage swing, and efficiency for a given bandwidth response is greatly reduced. This is illustrated by the comparison curve in Fig. 1 (p. 139) which shows that the peak power output for the class of output valve concerned is increased by some 40 per cent. The full increase could not be realised in practice due to the limitation imposed by the rate anode dissipation.

The grounded grid amplifier has, however, disadvantages. With this circuit the driver valve and the output valve act in series to supply the output load so that it would probably be necessary to modulate both valves, or alternatively the driver valve only, and a large wide-band low-efficiency driver stage, and possibly a further stage of voltage amplification, may thus be required in comparison with that needed for the same output valve used in a conventional or cathode-follower-driven grounded cathode circuit. Even so, bearing in mind that the driver stage contributes to the power output and that the output valve operates at increased efficiency into a higher load impedance (for a given band-width) the overall conversion efficiency of the transmitter is not likely to suffer. A further point is that filament of the output valve is at high modulated R.F. potential and this potential must be held off from the filament heating supply. In practice the grounded-grid amplifier and its modulated driver would both be operated as wide-band Class B push-pull amplifiers, and Fig. 8 shows a possible circuit of this type in which modulation is carried out on the grids of the driver stage only in order to reduce the modulating power.

It follows that since the mean anode current of both stages varies with the amplitude of the vision signal, their anode supply smoothing circuits would need to have a sensibly constant resistance characteristic for all modulation frequencies down to D.C. in order to provide a linear response to the sudden " step " in mean anode current, which occurs when the mean picture brightness changes from a black to an all white picture, and so avoid the excessive surges in the transmitted " black level " which would otherwise occur. Smoothing circuits which are so impedance corrected are relatively costly so that on this score it is desirable to restrict the number of high-power stages which are subject to modulation.

Special triodes for grounded-grid operation have been constructed in which the grid cylinder is extended to give more complete shielding between anode and filament, but so far none of these appears to be capable of giving power outputs much in excess of 20 KW per valve at frequencies above 50 Mc/s. and band-widths of the order of −1 db. at 2.75 Mc/s.

There are indications that future developments in valves of the CAT 21 class may produce significantly greater outputs at frequencies between 50 to 100 Mc/s., while at frequencies above 100 Mc/s. a wartime development known as the resnatron shows some promise. This device consists of a tetrode valve assembly in which the tuned circuits are constructed as an integral part of the electrode structure and are contained in the same evacuated envelope. The valve is said to be suitable for use as a grounded-grid amplifier of useful gain and that adequate tolerances for bandwidths up to 4 Mc/s. are obtainable with power outputs approaching 100 KW. A most useful improvement in the characteristics of large transmitting triodes would be an increase in the

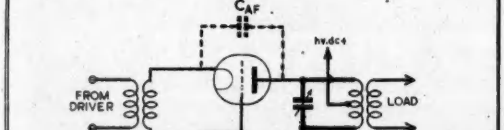


Fig. 7. Basic circuit of grounded grid amplifier.

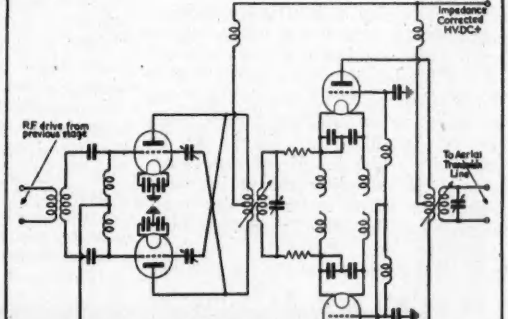
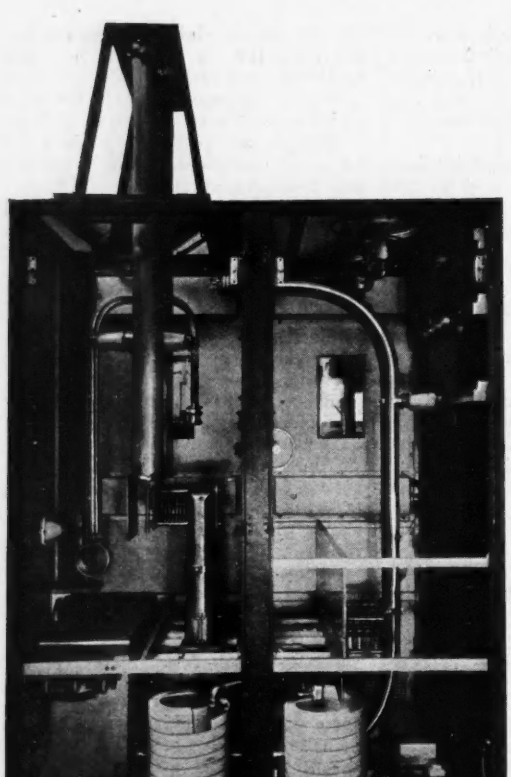


Fig. 8. Grounded - grid R.F. amplifier output stage driven by a grid-modulated wide-band R.F. amplifier.



The modulated grounded grid final R.F. amplifier stage of the Paris Television Transmitter. The valves are obscured by the central frame support. The ¼ wave filament lines leading to the heater transformers can be seen on the right while on the left is the balanced output coupling circuit with a variable air condenser feeding the twin concentric transmission lines which project through the roof. The grids of the valves are connected together through the variable transmission line on the left from the top end of which are hanging the flexible connectors for the valve grids.

Photograph by courtesy of Le Material Telephonique, Paris, associates of Standard Telephones & Cables Limited.

ratio of peak anode to peak grid current to reduce the grid power loss and modulating power and provide more output for a given peak filament emission.

Output Transmission Lines and Cables

The necessity of locating television transmitting aerials as high as is economically possible above the level of the surrounding country to obtain the maximum service area for a given aerial power implies that masts of 500 to 700 ft. high are likely to be adopted. The length of the transmission line feeding the aerial must be of the same order as the mast height, and the use of such long lines introduces two important considerations which tend to conflict in practice.

In the first place, the construction of the line should be such that impedance irregularities along its length due to spacing insulators, supports and joints are reduced to a minimum, as well as any residual mismatch between the line and aerial itself, since such irregularities produce wave reflexions, the time of travel of which in long lines is comparable with the modulation frequencies. Serious distortion of the received picture may result from these causes, the distortion becoming particularly evident at points of sharp discontinuity in the picture such as a rapid change from white to black or for a thin vertical line. In the latter case reflexion from a resonant aerial system terminating a 750-ft. transmission line may produce echo lines displaced from the original image at intervals of approximately 1/50th of the picture width.

The wave reflexions produced by insulators and joints give rise to a resultant reflected wave component in the line which continues to be radiated for a further time, equal to the time of travel of the wave over twice the length of the line, after the transmitter output signal voltage applied to the aerial has fallen to black level. This introduces a "step" of this duration in decay of the radiated signal and to minimise the amplitude of this step the ratio of the amplitude of the reflected wave component to the main wave component should be made as small as possible.

These effects have been described by E. C. Cork and J. L. Pawsey in an admirable paper* covering the investigations made on the 5 in. concentric copper tube feeder installed at the London Television Station (Fig. 10). It is shown that at operating frequencies in the neighbourhood of 50 Mc/s a single insulator of 1 $\mu\mu$F. capacity introduced into an 80 ohm line of this type produces, under steady carrier conditions, a steady reflected wave having a relative amplitude of approximately 1 per cent. Depending on the spacing of the insulators along the line the reflected waves they produce may either add or subtract. For insulators spaced at ½ wave intervals the waves add and produce a large resultant component which is a condition to be avoided. For quarter wave spacing the reflected wave from any one insulator is cancelled by the one from the next except for the first half cycle so the resultant reflected wave in this case consists of a series of half cycles, the fundamental component of which is about half the amplitude of that due to a single insulator. Thus with 1 $\mu\mu$F. insulators the amplitude of the "step" produced is only some 0.5 per cent. of the picture signal amplitude.

The practical implication is that the construction of the line should be such that it embodies either a very limited number of insulators placed in groups of two with ¼ wave spacing between the two, or a large number equally spaced at ¼ wave or preferably ⅛ wave intervals.

Secondly, a line of low attenuation is essentially in order that the maximum possible proportion of the already inefficiently generated transmitter power shall be transferred to the aerial.

The type of transmission line most likely to possess the least significant impedance irregularities is the flexible air spaced coaxial cable, using Polystyrene or ceramic disk insulators at close intervals to space the inner and outer conduction. Unfortunately

(*Continued on page* 204)

* "Long Feeders for Transmitting Wide Side Bands with reference to the Alexandra Palace Aerial-Feeder System." *Journal I.E.E.* 1939, 84, p. 448.

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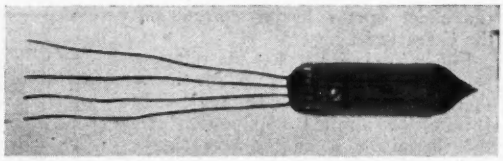
Thermistors

By W. ROSENBERG, M.Sc., A.I.R.E.*



THE word "thermistor" is compounded from "thermal resistor," and is applied to resistors with a high negative temperature coefficient. Positive coefficient thermistors are known but are not commonly used. The resistance elements are made from a mixture of certain metal oxides which are all semi-conductors, one of the most frequently used being uranium dioxide, which has a resistivity of 5×10^{3} ohms/cm³ at 0° C. and 2.8×10^{3} ohms/cm³ at 100° C. Fig. 1 shows the resistivity-temperature characteristic of uranium dioxide and another commonly used thermistor material, nickel manganese oxide. During manufacture the material is fired at a high temperature and is therefore not affected by subsequent heating to about 500° C.

In all practical thermistors the conduction is purely electronic, so that they may be used with direct or alternating currents.

A resistor which passes a current proportional to the potential difference existing across it—other conditions (for example, temperature) being kept constant—is sometimes called an ohmic or linear resistor, and thermistors are linear resistors within the meaning of this definition.

Now the current resulting from the application of an E.M.F *if allowed to flow long enough to heat the thermistor* will cause a change in its resistance and therefore in its voltage/current ratio. By a process of confused thought this change is sometimes adduced as a reason for saying that the device is a non-linear resistor, but in the interests of clarity, this error should be avoided.

2. Types of Thermistors

The resistance material may be formed into small beads, tubes or rods or into disks. The heating of the element may be achieved by passing current through it (directly heated types) or by heating a small resistive coil which is in thermal, but not electrical contact with the themistor bead (indirectly heated types). In a third type of thermistor the element is made large so that the resistance is mainly governed by the ambient temperature.

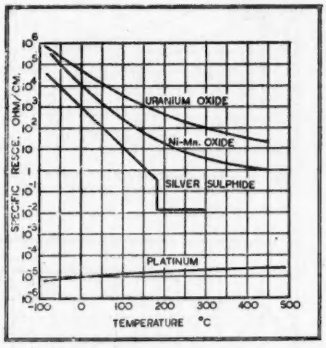


Fig. 1. Resistance-temperature characteristics of thermistor materials, with curve of platinum for comparison.

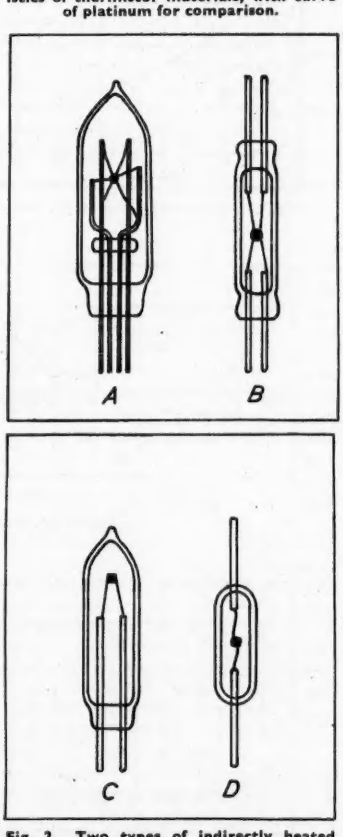


Fig. 2. Two types of indirectly heated thermistor (A, B), and two types of directly heated thermistor (C, D).

Some typical thermistors are illustrated in Figs. 2 A-D. In all except the disk thermistor, the thermally sensitive element consists of a small bead or tube (about .015 in. dia.) fused to .001 in. lead wires. The thin wires are spot welded to stouter leads or supports (*e.g.*, 22 S.W.G. wire).

Figs. 2A and B show indirectly heated types. The bulbs are usually air-filled and the resistance of the heater coils is generally 50 or 100 ohms.

Figs. 2 C and D show directly heated thermistors and Fig. 3 shows a typical disk thermistor in which the thermistor material is bulky. Owing to the large cross-section the current density is small and the heating due to the current is thus negligible.

3. Typical Thermistor Characteristics

The composition of the thermistor material may be made to have almost any desired characteristic. In this article, space only allows us to mention some typical values.

The "cold" resistance of the element is the resistance when the temperature is maintained at 0° C. This resistance can be made to lie anywhere between 1 megohm and 500 ohms.

There are three main characteristics which are of interest: the resistance/temperature curve, the resistance/power curve and the voltage/current curve.

Some resistance/temperature curves are shown in Fig. 4. The temperature coefficient decreases with increasing temperature (shown by the decreasing slope of the curve). This sets a limit to the useful working range at about 250° C.

Resistance/input power curves are shown in Fig. 5. It will be seen that large ranges of resistance are covered with modest power inputs.

Of great interest are the voltage/current curves shown in Fig. 6 (A, B and C). These show that the thermistor can act as a negative resistance. The curves refer to an indirectly heated thermistor and show

* Admiralty Signal Establishment.

the effect of the heater current on the characteristic.

Fig. 7 again illustrates the relation between voltage and current in a thermistor material. In region B (where the applied voltage is low) the thermistor is an ordinary ohmic resistance of positive slope. In region A the thermistor temperature rises rapidly and the incremental resistance becomes negative. In region D the temperature of the material is high and the temperature coefficient of resistance falls to a small value, and so the thermistor again behaves like an ohmic resistance with a positive slope.

Owing to its thermal capacity the change of resistance lags behind sudden changes in applied voltage. The delay is illustrated in Fig. 8 which shows the build-up of current through the thermistor after the sudden application of a voltage. The thermal time-constant of average thermistors lies between 0.5 and 4 seconds.

After the thermistor has been subjected to an ageing process, which is a normal part of manufacture, the characteristics are maintained even after long and rough usage.

4. Application of Thermistors

The use of a thermistor in a resistance thermometer is obvious. The resistivity is about 5-10 times that of a platinum thermometer, though the maximum temperature is limited to (say) 500° C.

At very high frequencies (*e.g.*, when detecting infra red rays) thermistors may be used as "absorption" radiation-indicators. They are considerably more sensitive than thermopiles or bolometers.

Owing to its negative temperature coefficient the thermistor may be used in conjunction with positive coefficient resistors in the design of temperature-insensitive resistance networks.

When a thermistor is placed in series with a relay of conventional design it will make the relay insensitive to voltage surges. This principle has considerable application in telephony.

The indirectly heated thermistor can readily be used as a remotely-controlled variable resistor. It thus has applications for gain control in feed back amplifiers and oscillators, or anywhere where a wide range of controlled resistance is required. The self-inductance and capacity are low so that the elements are usable at high frequencies. (Maximum current is usually about 50 mA).

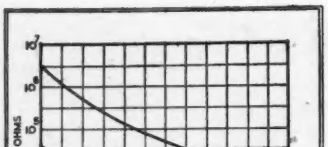


Fig. 4. Resistance-temperature characteristics of three thermistors.

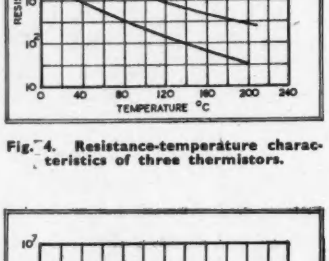


Fig. 5. Resistance-power input curves.

Fig. 7. Change of slope of characteristic over current range.
—*Bell Lab. Record.*

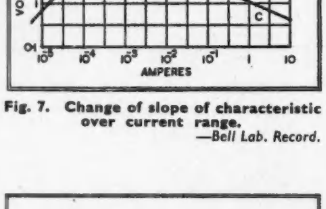


Fig. 8. Variation of current with time after sudden application of voltage.

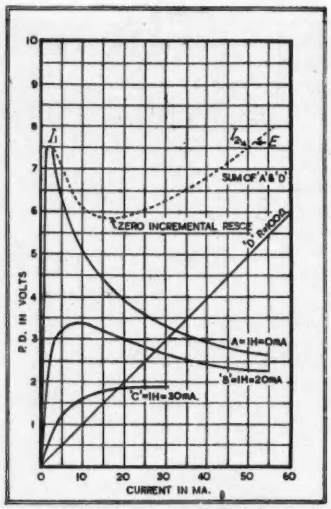


Fig. 6. Voltage-current characteristics of thermistors (A, B, C) with addition of a linear resistance characteristic (D), giving negative resistance effect.

Fig. 3. Typical disk thermistor.

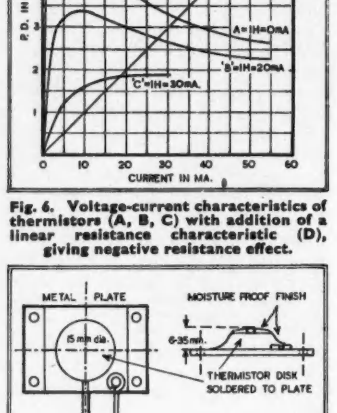


Fig. 10. Standard symbols for thermistors. (a) Directly heated in bulb, (b) without bulb, (c) mounted on metal plate, (d) indirectly heated in bulb. A device with a positive temperature coefficient is shown thus: —θ—

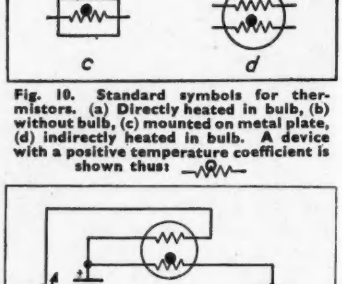


Fig. 9. Basic circuit of an oscillator utilising the thermistor characteristic.
—*See Brit. Pat.* 562,705.

If a thermistor is connected in series with an ohmic resistance the combination may be made to have zero incremental resistance at one value of current. Referring to Fig. 6, curve A gives the voltage/current relationship of the thermistor. D is the characteristic of a normal linear 100 ohms resistor and E is the result of combining D and A (*i.e.*, connecting the thermistor and resistor in series). The resulting curve has zero slope at one point. In this region the resistance to small changes in current is zero. At I_1 and I_2 the voltage is equal, hence these two points represent stable states for the circuit. This may be made the basis of a useful trigger circuit. The circuit is tripped from one stable state to the other by the application of alternate positive and negative pulses.

Fig. 9 shows an indirectly heated thermistor connected in series with a parallel resonant circuit. Owing to the negative resistance characteristic of the thermistor the circuit can be made to oscillate. Adjustment is made by varying the heater current. The inherent thermal capacity of the oscillator limits the maximum frequency of oscillation. Very small thermistors have been made which are capable of oscillating up to about 5,000 c/s.

The circuit of Fig. 9, when not actually oscillating, can be made to have a very high Q at low frequencies. This is because the total resistance can be made very low. The property is particularly valuable because conventional high-Q circuits require very bulky coils at low frequencies.

One of the most important uses of thermistor in short-wave radio technique is the measurement of H.F. and U.H.F. power. Elements suitable for mounting in waveguides and co-axial lines (Figs. 2B and 2D) have been used at all frequencies which have so far been explored.

In this account only a few applications have been mentioned. Others will no doubt occur to engineers and physicists. However, this account although brief will show that the thermistor is a versatile circuit element.

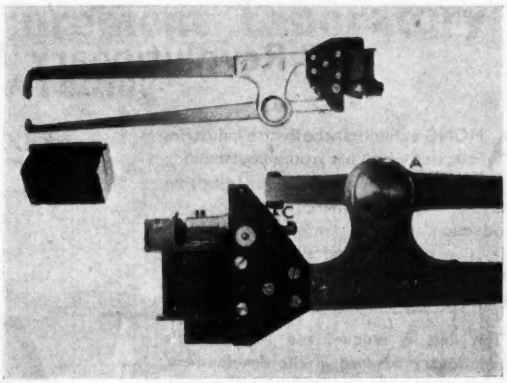
This article is published with the approval of the Board of the Admiralty, and the author is indebted to Messrs. Standard Telephones and Cables, Ltd., from whose reports some of the information has been extracted.

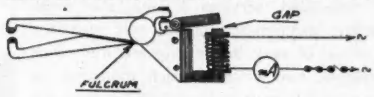
[1] Bell Laboratories Record, December 1940, Vol. XIX, No. 4.

The Z-Callipers

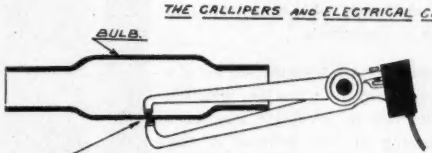
By

A. G. LONG*





THE CALLIPERS AND ELECTRICAL CIRCUIT.



WALL THICKNESS BEING MEASURED.

Fig. 1 (*right*). **Callipers used to measure bulb thickness, and (b) electrical circuit.**

Fig. 2 (*above*). **Close-up of coil and contact, and view of complete callipers.**

IN the manufacture of vacuum apparatus it is frequently of importance to measure the thickness of bulb walls, particularly of cathode-ray tube and X-ray tube bulbs.

These are of such a shape that the use of ordinary leg callipers is impracticable, and alternative methods of measurement, such as optical or radiographic, are tedious in mass production.

The callipers described were designed to overcome the difficulties of direct measurement and have proved sensitive and satisfactory in practice. The term "Z-callipers" has been applied to them from the principle of variation of impedance (Z) on which they depend.

Fig. 1 shows the callipers with the coil cover box in place. The shape of the jaws in this particular case was chosen to enable the thickness of glass bulbs of the type shown in the figure to be measured. It is suggested that either the jaws should be made removable to meet different types and shapes of work, or that separate callipers be used to meet different needs. The electrical circuit is straightforward and is shown in Fig. 1b. The actual calliper shown (Fig. 3) was constructed from a standard relay coil and the complete unit was used with the exception of the contacts, which were removed. The calliper legs are made from $\frac{1}{4}$ in. brass, and the fulcrum is made by passing a large brass pin with locking nut through the joint of the callipers. The moving armature of the relay unit is coupled to a strong brass bridge piece, which in turn is arranged as a rocking arm with a second fulcrum position placed in the body of the end unit; a brass bush "A" (Fig. 2) provides the bearing position for the rocking arm. Opening the legs of the calliper will cause the rocking arm to open the magnetic gap on the coil unit, thereby reducing the impedence of the winding, and allowing more current to flow in the coil circuit; this movement is transmitted to the rocking arm via the point and adjustable anvil "C" (Fig. 2). These last two pieces are made from hardened steel. The calibration of the callipers is undertaken by placing known thicknesses of material between the jaws and reading the resulting current on the milliammeter. The scale of the instrument can then be read direct in millimeters, or inches as desired.

Some small difference will result in the readings due to mains voltage changes and frequency changes, but these are not likely to be serious.

* Messrs. Newton & Wright

A Revolutionary Mobile Television Unit

AMONG exhibits at the British Industries Fair, one which has aroused outstanding interest is the Pye Mobile Television Station. Everything required for the production and transmission of a complete television outside-broadcast feature is contained in a medium-sized vehicle of the 28 H.P. "shooting brake" type.

The unit is unique, and represents a revolutionary advance in the development of television services. Even the most cursory examination of the unit reveals a number of very interesting features. For example, two cameras, each mounted on specially designed self-steering trolleys, are folded and neatly housed during transit in the rear flap of the vehicle.

Two-channel monitoring is carried out at a very compact console, making possible complete control by a single operator. Remote focusing of the cameras is also carried out from the console by means of a servo system.

View of the complete vehicle. The directional antenna can be seen at the top; the folded dipole alongside being the communications aerial. One of the cameras, unshipped and ready for action, is seen at the right.

General view of the interior, showing the operator at the control console. Beyond the driver's seat can be seen the transmitter, the radio-telephone equipment, and, below, the power unit.

A single transmitter only is used, accompanying sound being inserted into the picture waveform by the use of the Pye Videosonic System.* The antenna radiating the transmitter output on 660 Mc/s is hydraulically elevated to some 35 feet, and can be orientated as desired. Communication with the main station is by a built-in Pye Radio-Telephone equipment, while power for the whole unit is provided by a 3 KW generator driven by the car engine.

It is evident that much imaginative engineering has gone into the development of this apparatus, and engineers will await further details with considerable interest.

* See *Electronic Engineering*, Dec. 1945, p. 814.

A Modern Vibration Measurement Laboratory

Part 4—Fatigue Testing

By D. M. CORKE*

IN applications where unnecessary weight is a serious handicap on performance, materials must be selected with care and used to the limit of their capacity. The earlier articles of this series have described the various methods available of measuring vibration deflections and stresses in machines and structures, and it has been shown that the vibration engineer can check his calculations of vibration resonant frequencies by field tests, and can quickly determine the stresses to which his machines will be subjected under service conditions by electrical strain measurements. It should be noted here that it is sometimes comparatively easy to calculate vibration frequencies, but virtually impossible in any case to forecast stress levels because of the difficulty of determining the magnitude of the damping factors in the vibrating system. There is an analogy that is often used to explain electrical circuit phenomena to students with some knowledge of mechanical engineering which may be usefully applied here in reverse. It is not, however, generally known that this analogy between electrical and mechanical oscillations is precise, and that the relations between inductance, capacitance, and resistance in an electrical circuit are exactly the same as those between inertia, flexibility, and damping in a mechanical vibrating system. Likewise, electrical charge is the analogue of displacement, current of velocity, and voltage of mechanical force. Hence, using this analogy, it can be said that the vibration engineer knows the inductance and capacitance values in his circuits, but cannot calculate the charges and currents because the resistances are unknown. This is the more serious because, in general, the "Q" values of mechanical systems are very large, and very large magnifications of displacement and stress may be achieved under resonant conditions. It is in the avoidance of this by proper design that a large part of the art of vibration engineering lies.

Another section of the art involves the improvement of the resistance of materials to vibration stresses. It is a matter of fairly common knowledge that materials will fail at stresses well below their elastic limits if the load is reversed a sufficient number of times, this phenomenon being known as fatigue. The ultimate fatigue strength of a specimen of perfect design and workmanship would be determined by its internal metallurgical structure alone, and could, in the ordinary way, be left to the metallurgists; but the actual strength in fatigue is, in practice, affected by mechanical factors such as the shape of the member and the fineness of finish of its surface. Sudden changes in the outline, sharp angles, tool marks, and accidental scratches tend to produce local stress concentrations that magnify the structural stresses in the member so greatly at these points that failure occurs at low indicated stress levels. It may well be pointed out here that the very general delusion that a metal which has failed in fatigue has crystallised at the point of failure is quite incorrect, the metal undergoing no inherent change whatever, as all metals are crystalline in the solid state.

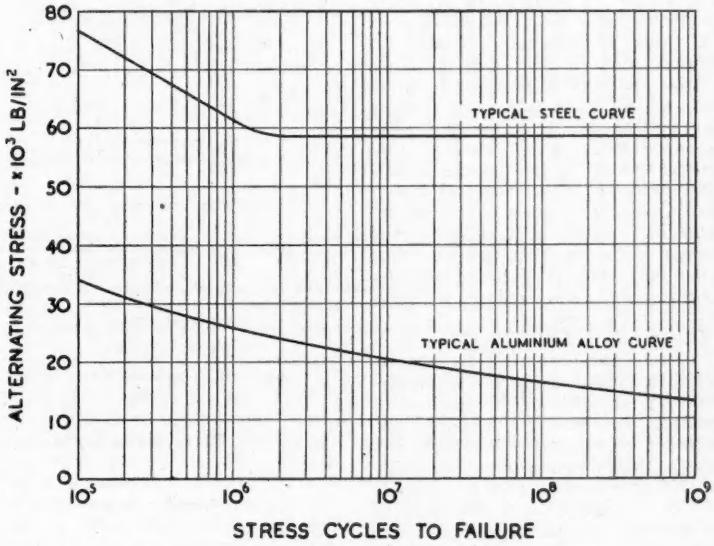


Fig. 1. Representative fatigue curves.

Fatigue Curves

The vibration engineer cannot yet reliably estimate the weakening effects produced by the various stress raisers that may be present in a given member, or the improvement in resistance that can be brought about pre-treatments such as cold working the surface, and has to fall back on the statistical results of fatigue tests on a number of sample specimens. Each specimen of a batch is tested at a definite vibration stress level until failure occurs, or until a sufficient number of stress cycles have been endured to make it certain that failure will not take place. Plotting these results as stress against stress cycles endured gives the fatigue curve for the batch, and, with steels, the stress value at which the curve levels out is taken as the maximum safe vibration stress for the design. In the case of aluminium and magnesium alloys, however, there is no stress below which failure will not occur, *i.e.*, no flattening out of the fatigue curve; and these materials will always fail if the vibration is carried out for long enough. With such alloys, the number of

* Vibration Department, de Havilland Propellers, Ltd.

stress cycles to which the member is likely to be subjected in the course of its working life must be estimated, and a stress level chosen from the fatigue curve which will guarantee a life as long as that required. Fig. 1 shows representative fatigue curves.

In order to carry out any extensive programme of fatigue tests, many specimens must be tested because of the wide experimental scatter in results; and, in the case of light alloys, individual specimens must undergo, for some applications, up to 500 million stress reversals. For these reasons, it is obvious that fatigue testing by mechanical means, where rates of stress reversal higher than 3,000 cycles per minute are uncommon, can be a very long and expensive business, tests going into three months per specimen running continuously, and using a large amount of power.

One way of shortening the tests is to vibrate the specimens by electromagnetic means at higher frequencies than can be achieved by mechanical methods, and very much power may be saved by vibrating them in resonance at their own natural frequencies. In this way, specimens may be tested at ten or twenty times the speed of mechanical fatigue tests, and at a tenth of the power consumption, because of the magnification of movement and stress that takes place under resonant conditions.

Regenerative Testing

A very efficient and satisfactory way of carrying out tests of this type is to run the fatigue test rig and its associated electrical equipment as a regenerative circuit, and it is useful in the case of larger specimens to run them in pairs, vibrating in phase opposition like the tines of a tuning fork, so that the root clamping reactions are largely balanced. A sketch of such a rig is shown in Fig. 2. Each specimen has, fastened to its tip, a magnetic armature which is attracted once per cycle of excitation current towards the pole pieces of the symmetrical magnet system, which may be polarised by a winding on the central core, or by permanent magnets built into the system.

A linear vibration pickup, which may be any one of the types described in the earlier articles, a photo-electric device, or even a microphone, is fastened to a convenient point on the test rig so that it generates a signal at the frequency of vibration of the specimens. This signal, which is usually proportional to the amplitude

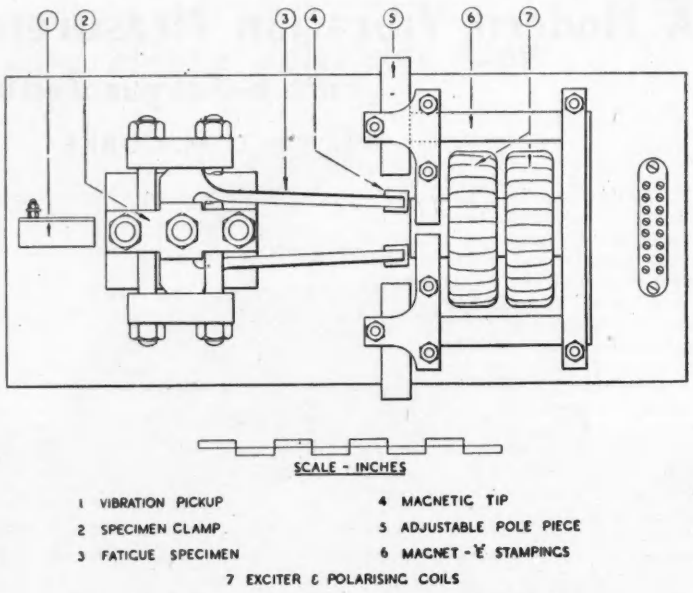


Fig. 2. Rig for testing specimens cut from propeller blade roots.

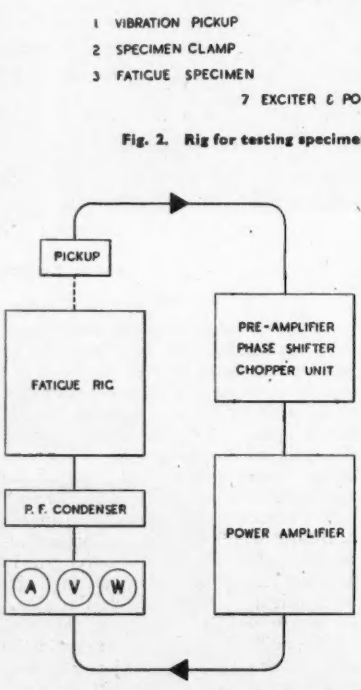


Fig. 3. Block diagram of regenerative electro-mechanical fatigue test system.

of vibration of the specimens is fed through a phase adjusting circuit to the input side of the power amplifier that supplies the excitation current to the test rig magnet. This coil is tuned by a power factor correction condenser, and it can be seen that the whole electro-mechanical system may, by adjustment of the phase of the pickup signal, be made regenerative, and that it will oscillate at the natural frequency of the test specimens. By this it will be seen that a very high overall efficiency can be obtained, as the specimens are always on resonance even though the frequency may tend to fall slightly as fatigue sets in. The only power required is for the I^2R losses in the exciter coil, the small eddy current losses in the magnet core and specimen armatures, and the windage and mechanical hysteresis losses in the specimens themselves.

Stability of Running

This type of drive arrangement, although efficient, suffers from instability, as a small change in specimen amplitude is returned to the exciter coil as a proportional variation of current tending to raise or lower the amplitude still further. Random disturbances, both in the mechanical and electrical parts of the regenerative circuit, tend to produce these sudden changes. A chopper device has therefore been developed which, incorporated in the circuit, produces from the pickup voltage a signal of the same frequency but of fixed voltage that can be adjusted in amplitude and phase to drive the specimens at whatever stress level has been decided. They will then keep running at that

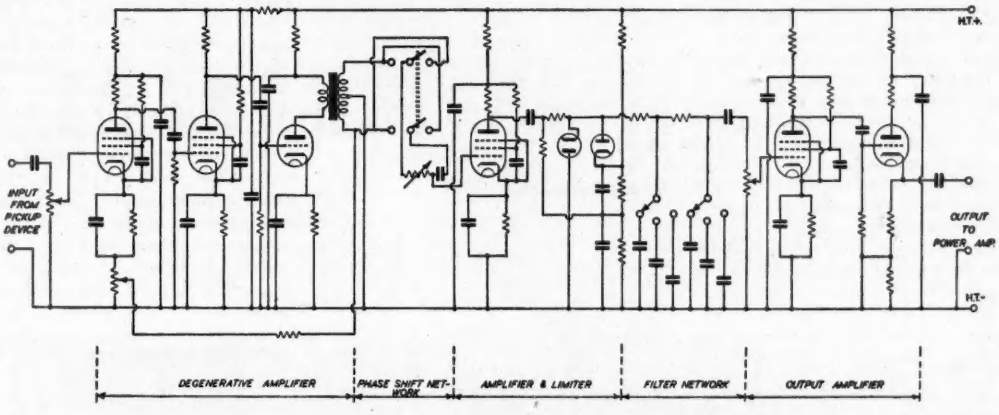


Fig. 4. Circuit diagram of pre-amplifier, chopper, and phase adjuster unit.

amplitude and at their own natural frequency until failure occurs. Only changes in the power needed to keep them in resonance will then produce alterations in amplitude and stress, and these are gradual enough to be left to ordinary supervisory inspection. The large increase in power required when failure takes place, due to the increased hysteresis losses in the fractured specimen, and the sudden fall in resonant frequency are very marked and cannot be overlooked, even when the initial crack is quite invisible to the naked eye.

A block diagram of the electromechanical circuit is shown in Fig. 3, and a detailed circuit diagram of the chopper and phase shift unit in Fig. 4. It will be seen that this consists of a conventional degenerative preamplifier, with the feedback signal taken from the secondary of the coupling transformer. This is followed by a simple resistance-reactance phase adjuster, and by a voltage amplifier stage, with a pair of voltage limiting diodes which cut off the tops of the amplified signal sine-wave at a fixed level. The resulting constant voltage square wave, which is still of the same fundamental frequency as the original signal, is fed into the low-pass filter network. This cuts the corners off the square wave, and passes a substantially sinusoidal constant voltage to the output stage, which feeds the possibly remote power amplifier of the test rig through a cathode follower. The whole phase-shift, limiter, and filter unit, with its amplifiers and power pack is built as a standard rack

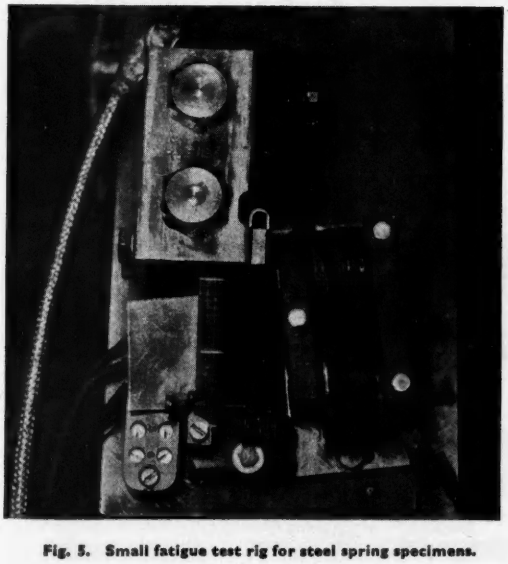


Fig. 5. Small fatigue test rig for steel spring specimens.

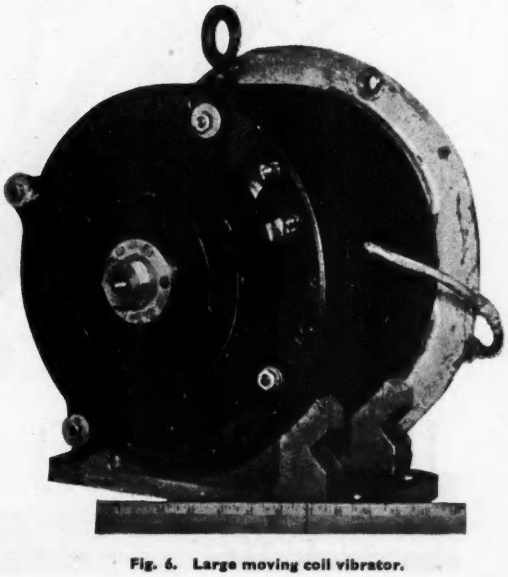


Fig. 6. Large moving coil vibrator.

mounting unit, so that it can be incorporated in any fatigue test hook-up. It is suitable for test rigs of any size, at frequencies from 10 to 1,000 c/s. For difficult cases, where it is necessary to run a specimen in a high overtone mode, a band-pass filter can be incorporated in the circuit. The amplitude limiting "chopper" device, and the reaction-less type of mounting of two test specimens have been the subject of a patent application.

In Fig. 5 an example of one of the smaller fatigue test units is shown, for testing small sections of steel spring used in aircraft components. The vibrating spring specimen and the energising magnet system can be clearly seen, together with the small scale on which the vibration amplitude can be read. The small box fastened to the specimen clamping block contains an acceleration-driven piezo-crystal which supplies the signal voltage to the driving amplifier. A rig of this size requires about 5 watts of power, while that of Fig. 2 uses some 30 watts. One of the largest rigs yet set up, to fatigue aluminium alloy propeller blades 7 ft. long, uses a very large moving coil type vibrator, the blade being suspended at its vibration nodes, and using between 40 and 120 watts of power, depending on the mode and amplitude of vibration. A photograph of the vibrator, which was designed and built by de Havilland Propellers, Ltd., is shown in Fig. 6. Even larger rigs, using up to 2,000 watts are projected.

Stress Calibration

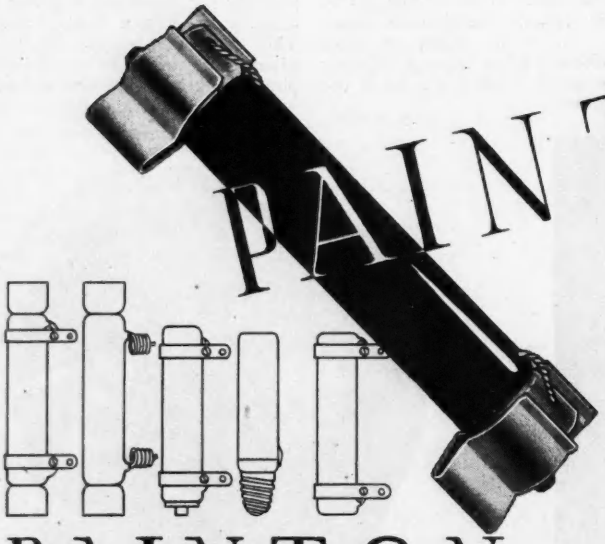
To determine the stresses at which the specimens of a batch must run, a calibration of one or more individuals is carried out, with strain gauges cemented close to the point at which failure is known or expected to occur. From this, the relation between stress and the amplitude at an arbitrary index position, usually the free tip, is found at the most suitable resonant frequency of the specimen; and future specimens can then be run at appropriate amplitudes. This procedure can be used for most large and medium sized specimens because of the large range of sizes of strain gauges available, which, in special cases, can be bent round fillets, or inserted in holes and notches.

In the case of very small members, however, where stresses change rapidly over very short lengths, or where the addition of a gauge would materially affect the stiffness and mass of the member, other methods must be used; and a technique has been developed of calculating the stresses from the deflected form under vibration as measured directly by a calibrated microscope or indirectly from a photograph. This was used, for instance, in the case of the spring specimens shown in Fig. 5, but will not be described in detail as it does not fall within the scope of the present paper.

Acknowledgments

The authors would like to express their indebtedness to Mr. R. N. Hadwin who founded and built up the Vibration Department of de Havilland Propellers, Ltd., and to their colleagues under him, who, together, have done so much to advance the techniques of vibration research in this country.

They would also like to thank de Havilland Propellers, Ltd., for their permission to publish these papers.



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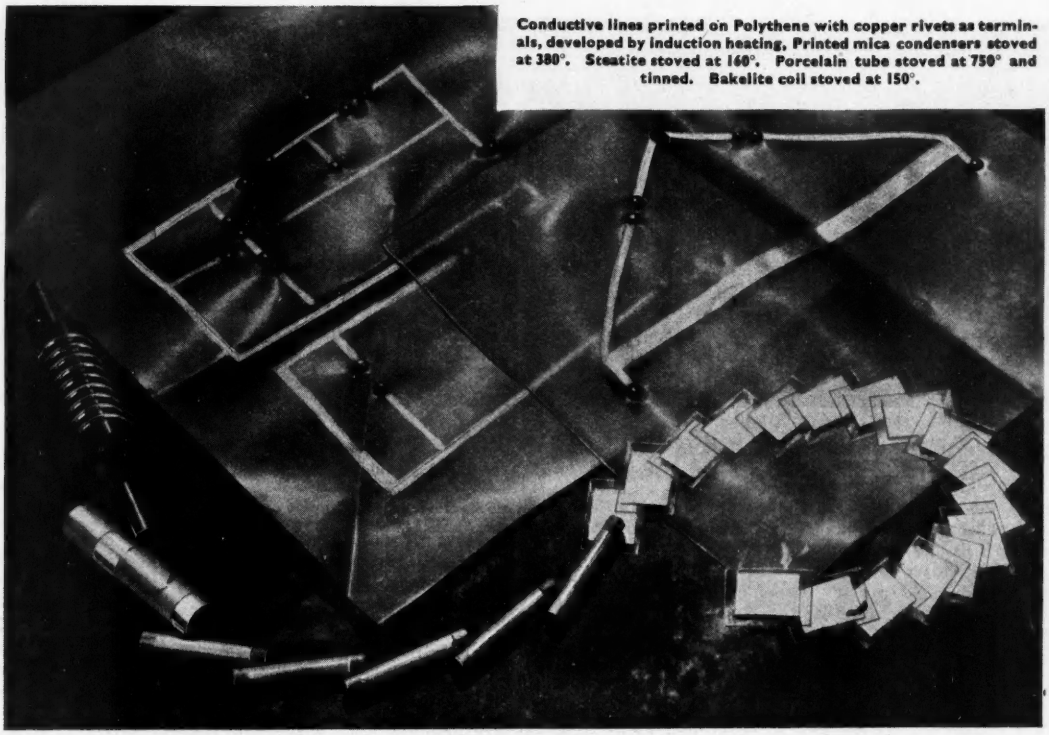


Conductive lines printed on Polythene with copper rivets as terminals, developed by induction heating. Printed mica condensers stoved at 380°. Steatite stoved at 160°. Porcelain tube stoved at 750° and tinned. Bakelite coil stoved at 150°.

New Types of Silver Coatings

By PETER P. HOPF*

CONSIDERABLE interest has lately been shown in the silvering of non-conductive materials by means of applied silver coatings for various electrical purposes and in particular for the printing of circuits on steatite bases. The processes employed vary according to the effect desired. For the silvering of mica, stencils are usually employed through which the solution is sprayed. The same applies to certain types of ceramic condensers, although in this field dipping and brushing are more popular. For the printing of circuits the most successful technique so far employed has been that of silk screen printing.

All these methods, but in particular the printing method, have been devised primarily to suit the materials available for silvering and these materials severely limit the introduction of mass production methods in the field of silvering on non-conductive carriers. Silvering preparations are usually finely divided forms of silver, silver oxide or silver carbonate suspended in organic media such as pyroxylin or other cellulose derivatives and an organic solvent. It is necessary that a flux be added to these materials to assure good cohesion and adhesion of the film. Similarly, resinates of silver are employed for the silvering of mica in particular. These are diluted with organic solvents, consisting wholly or partly of essential oils. This type of material dries after spraying and melts again during stoving operations. This property excludes it from uses where fine printing and sharply defined coatings are required.

It seems patent that in the printing of circuits with any of the above materials the silk screen press is the only means available to supply a thick enough coverage of paste to give the desired conductivity. All non-heat-resisting carriers are automatically excluded by the high stoving temperature required to obtain adhesion and to reduce the oxides to metallic silver. It is, of course, vital that no organic material likely to influence the conductivity of the coating is left after firing. When this silver coating has to be soldered to, the flux becomes a serious disadvantage, as it makes the silver tend to dissolve in the solder. Similarly, with high frequency ceramics which have to be partially tinned after silvering, the silver tends to dissolve in the tin more readily, thus causing air spaces and variations in conductivity.

These laboratories have approached the problem from a different angle and after numerous tests in conjunction with manufacturers of electrical equipment, have evolved a silvering preparation and technique which overcomes all difficulties of the above nature, as well as helping to widen the choice of non-conductive materials to be used in the manufacture of condensers and as bases for printed circuits, etc.

The material is a stabilised colloid of metallic silver containing a minimum amount of silver oxide and no other inorganic matter whatsoever.

* Ward, Blenkinsop & Co., Ltd.

The organic matter present has to be volatile below 300° C. We have successfully made such preparations containing up to 70 per cent. silver. It is important that such preparations contain no resinous matter or materials tending to polymerise on heating, however slight that tendency may be. This rule excludes even turpentine as a solvent.

Preparations made in this fashion have additional advantages in use which cannot be fully enumerated here, but attention ought to be drawn in particular to some of the advantages for the printing of circuits in mass production. The silk screen printing method cannot be regarded as wholly satisfactory, and although the initial expense of the press is small, its operation is a skilled job and slow. Continuous cleaning of the stencils requires more time than the actual printing and the maximum degree of exactness reached is far below the standard performance of a letter press or offset press. It seemed obvious that a material like the one described above could be used on an offset press with improved results. A special press was constructed for the purpose, being a slight modification of an ordinary offset press and although for experimental purposes it was hand operated, it recommends itself as a cheap means of obtaining mass production, as it may easily be mechanised. (Fig. 2.)

The ink pad (E) made of polished steel is self-rotary and two gelatine cast rollers (D) pass continuously over this pad to transfer ink to the zinc letterpress block on carrier (A). In the same motion the specially soft rubber blanket on roller (C) transfers the print on to the carrier (B) on which the object to be printed is located. This machine will print up to two-thousandths of an inch in thickness of ink and with an ink containing 70 per cent. of silver metal this thickness will have a low enough surface resistance to suit most purposes.

One of these purposes is the printing of aerials in spiral "pancake" fashion on the inside of a radio receiver case. As will be seen later, the basic material is not limited to mica or ceramics, but polished wood, plastics, etc., may be used in conjunction with this material and method of silvering. In some cases, however, the amount of silver so deposited will not suffice to give the desired conductance, especially where hairlines or lines of small width are to be printed. In these cases it is possible

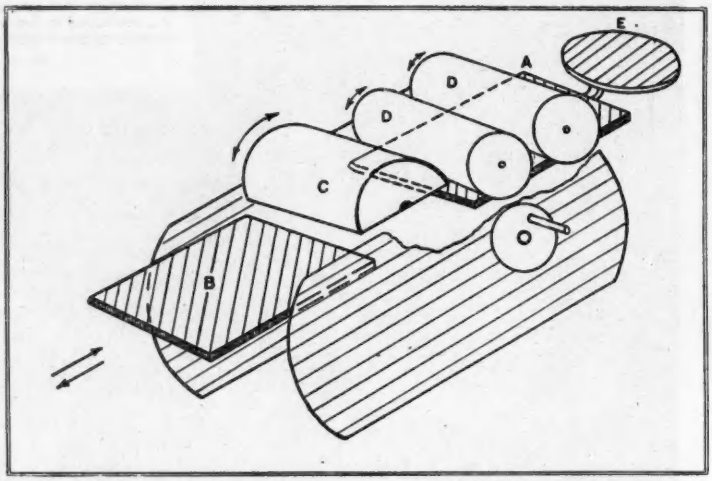


Fig. 2. Diagrammatic sketch of offset printing press modified for printing circuits.

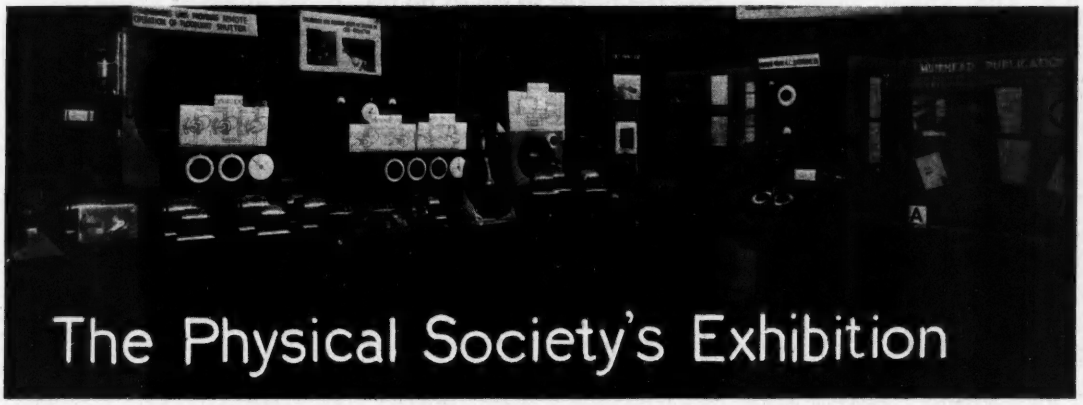
to build up the silver coating without impairing the shape outlines of the print. The process is similar to the one used for printing resists on metals in ordinary etching processes.

The colloidal silver material, which may be made of varying viscosity over a wide range may also be made readily as a low melting fine powder. The print will not dry quickly but will stay sticky for a long time. It may therefore be dusted with this powder, followed by a dusting with french chalk to clear any silver particles from uncoated places. By intermittent heating to about 60° C. and dusting, the silver-containing coating may be built up to any desired thickness.

As already stated, such silvering materials offer the advantage of not running or melting again after the solvent is evaporated and giving an even and adherent coating of pure silver at 300° C. At temperatures as low as 110° C., however, coatings which are permanent and adherent are already obtained of a conductivity equivalent to 75 per cent. metallic silver, the remainder being silver oxide. Such coatings, although presenting the appearance of metallic silver and quite adequate for decorative purposes, are not sufficiently conductive for most electrical purposes. They are, however, amply conductive for subsequent electro-deposition of silver, copper, or nickel. If the unsilvered parts of a plastic article are masked by a water-repellant substance, say, beeswax, satisfactory metal coatings of great mechanical strength may be obtained. This method, although desirable for many purposes, has the disadvantage of being limited, as owing to the nature of the basic material such electrodeposits have to be applied in most cases initially from cold acid or neutral plating baths.

An alternate and far more elegant method of silvering plastic material with such silver preparations, which opens entirely new possibilities in electrical design and construction, is possible by the use of high-frequency eddy current heating. Condensers may, for instance, be made of plastic materials of highly desirable electrical properties such as Polythene. Great progress has been made with high frequency heating machines in the last decade and designs to suit all requirements are on the market. A piece of plastic material coated with the silvering preparation placed between the electrodes will not become appreciably heated, while the coating, which is of low conductance initially, is gradually warmed. As the temperature in the coating increases, its conductivity increases and the current will have to be reduced. When a temperature of 300° C. is reached in the coating this will consist of pure metallic silver, while the plastic carrier is only just warm to the touch. In this manner many highly interesting applications of the silvering of non-conductive materials can be effected. Outstanding as an example illustrating the possibilities of this method is the manufacture of condensers by silvering films of polythene. Such a film of, say, four-

(*Concluded on p.* 198)



The Physical Society's Exhibition

Some of the apparatus on view at the Physical Society's Exhibition held at Imperial College, South Kensington, London, S.W.7, on April 9th. to 12th. 1947.

Properties of Lead Sulphide Cells as Infra-Red Detectors *(Dr. F. E. Jones)*

Within the region of its spectral sensitivity (about 1-3.5 microns) the lead sulphide photo-conductive cell is the fastest and most sensitive detector known. It has found many applications in industrial and academic problems in addition to its use in spectroscopy. It is to be expected that many more applications for the cell will be found when its properties become more widely known.

Linear Coil Winding Machine *(Mr. J. N. Morley)*

This machine has been designed to wind potentiometers whose resistance/length law is linear to one part in 8,000 of the total resistance. This accuracy is necessary since variable linear potentiometers have become essential components in all electronic computing devices. At present the precision obtainable is restricted by inaccuracies in the potentiometers.

An automatic wire feed tension unit is incorporated in the winding machine and this makes it possible to wind 50 s.w.g. (0.0010 in.) nickel chrome wire without fear of breaking. It is possible to wind a pitch as small as 0.001 in. with an infinitely variable speed adjustment from 0 to 400 r.p.m. Tests on the products of an earlier version of the machine before certain improvements had been incorporated showed that it was possible by correct speed of winding to produce a pitch of 0.0025 in. accurate to 0.0001 in.

Circular Time Base Frequency Comparator *(Mr. W. H. Ward)*

The comparator is designed to compare accurately very stable oscillators which are very close in frequency. It can be used for frequency comparisons in a variety of other cases.

Two signals are fed into the instrument, which employs a cathode ray tube display. The two signals produce a circle split into bright and dark arcs. By observing this pattern, the frequency of either signal can be obtained in terms of the other. Means are provided for simplifying the observation of patterns which have many arcs.

Equipment for Determining the Characteristics of Geiger-Müller Counters

This includes four equipments:

(a) *An Automatic Plateau Plotter* which automatically records on a strip of paper the variation of counting rate of a Geiger counter with the applied voltage.

(b) *A Cathode Ray Monitor with Pulse Interval Discriminator.* This consists of a cathode ray monitor which is triggered by the pulse from a Geiger counter and displays the pulse on the cathode ray tube. The pulse interval discriminator ensures that the monitor is only triggered by pulses which have been preceded by a pulse-free interval sufficiently long to ensure that there are no ions present in the Geiger due to a previous striking.

The apparatus is useful for the general checking of Geiger counters, and it can be used for the measurement of pulse amplitude and the estimation of the dead time and the recovery time.

(c) *An Automatic Dead Time Indicator.* This device gives a rapid measurement of the time during which a Geiger counter remains insensitive after the extinction of the discharge.

(d) *A Pulse Interval Analyser.* This is designed to detect any non-random distribution of the pulses given by a Geiger counter. Since most spurious counts are of a non-random nature, the presence of such counts can be detected and their time relationship with true counts ascertained.

Telecommunications Research Establishment, Ministry of Supply, Malvern.

Voltage Stabiliser *(R. J. Hercock)*

This stabiliser, adapted for the precise control of standard lamps, can be adjusted continuously to give an output voltage of 50-150 V (using D.C. input at 230 V), the maximum power output being 250 W, subject to a limiting current output of 2½ amp. Percentage voltage variations in the output are reduced to 0.0003-0.001 of the percentage input variations. The control voltages are derived from a combination of the input and the output voltages, using known circuit elements.

Special Plates for Recording Tracks of Nuclear Particles

Recent research has resulted in the production of a range of special plates intended for use in nuclear work. These plates consist of thick coatings of fine-grain, highly concentrated emulsions. Tracks of alpha-particles, protons, deuterons, and particles resulting from nuclear fission can be recorded. The high concentration of fine grains results in the production of well-defined tracks, and the small number of fog grains produce a minimum of interference with the record.

Ilford Limited,
Ilford, Essex.

Applications of Crystal Rectifiers

Crystal rectifiers developed for use in centimetre wave radio and radar equipment may be used in many applications outside the cm. waveband, where size, mechanical strength and absence of heater connexions are important considerations.

A rectifier type voltmeter with capacitance dividers for extending the voltage range has been developed. Without dividers the voltage range is 0-50 volts from 50 c/s. to 5 Mc/s. With appropriate dividers the voltage ranges may be extended to 250, 1,000, 5,000 and 10,000 volts respectively over the frequency band 200 Kc/s. to 5 Mc/s.

A special feature of the design is the double circuit, symmetrical about earth, which enables measurements to be made of the voltage between two points when either point or any intermediate point is earthed and at the same time maintaining the D.C. circuit and meter case at earth potential.

A convenient unit for measuring or monitoring current in the megacycle region is provided by a radio frequency

current meter adaptor, comprising a toroidal wound input transformer and crystal rectifier. Used in conjunction with a 0-1 milliamp D.C. meter, the unit is calibrated to read 0-1 amp. over the frequency range 95-105 Mc/s.

Other frequency ranges may be covered by suitable design of input transformer.

High-Frequency Voltage Rectifier Unit

The high voltage supply unit with high frequency generator delivers 20 KV and 0.5 milliamps D.C. It consists of a normal type mains unit feeding a power oscillator which operates at about 120 Kc/s. The output from the oscillator is applied through a step-up transformer to a voltage doubler stage which employs specially designed rectifier valves with directly heated low wattage cathodes. The latter are heated by high frequency power derived from auxiliary windings on the H.F. transformer. Reduction in size, weight and cost, with greater safety from high voltage shock, are the chief features inherent in the design.

British Thomson-Houston, Co. Ltd., Rugby.

The "Skiatron"

This instrument, conceived and developed in the Scophony Laboratories, is a form of cathode ray tube in which the electron beam striking the screen, instead of causing fluorescence, produces an image of varying opacity which can be examined or projected by ordinary optical methods using conventional high intensity illumination sources instead of relying on the somewhat weak light emitted from the usual fluorescent material.

Since the image produced will remain on the screen as long as is required and until simple steps are taken to cause it to die away, many investigations can be carried out with it without the trouble and delay of using photographic means of recording as has hitherto been necessary.

Many industrial and research applications seem possible and developments are proceeding to adapt it for use in electro-encephalographs, electrocardiographs and for the studying of single stroke transients of all kinds, and to photo-telegraphic equipment.

Scophony, Ltd., Town Hall Buildings, Wells, Somerset.

Cloth Guiding Device and Control Equipment

A photo-cell control signal is derived from the lateral position of the cloth selvedge and is used to adjust the angular position of a guiding wheel, so that the cloth leaving the guiding wheel is always correctly positioned for entry into a processing machine. The control signal is suitably amplified and operates a split-field motor-generator which in turn varies the angular position of the guiding wheel.

The machine has been developed in collaboration with Messrs. Tootal Broadhurst Lee Co., Ltd., who are the owners of British Patent No. 542323 and corresponding foreign patents on the actual guiding device.

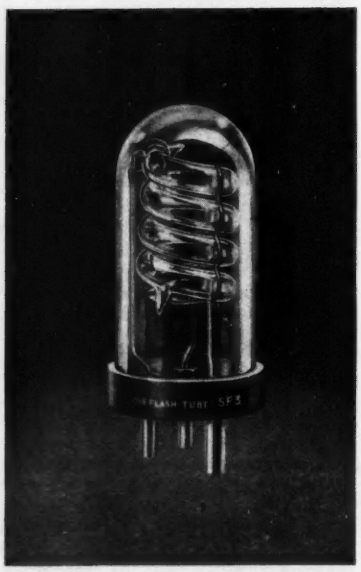
Ferranti, Ltd., Moston, Manchester, 10.

Evaporation Plant for use with the Met-Vick type E.M. Electron Microscope

The plant described is intended primarily for the deposition of silica on specimens for use in the electron microscope. It is also equally suitable for the deposition of gold or other metals used in shadow-casting techniques. It consists essentially of a high vacuum pumping plant, comprising an oil condensation pump and a mechanical rotary vacuum pump, arranged to evacuate a suitable bell-jar in which the specimen for treatment is placed. An adjustable electrical supply is provided for heating the filament type heater carrying the material to the evaporators.

The plant is designed as a self-contained unit and in appearance it is like a small enclosed cupboard, having a bell-jar on top. The dimensions of the framework are approximately 2 ft. 9 in. high, 13 in. wide and 2 ft. 8 in. long and the bell-jar is approximately 8 in. diameter by 12 in. high. On one end are mounted the various switches and the Variac for filament supply control. On the top are the knobs of two vacuum taps, which are used to select the duty for the rotary vacuum pump, and on the side is the knob of the high vacuum flap valve, which isolates the oil condensation pump. These three valves are so arranged that the bell-jar can be opened to atmosphere and re-evacuated without the delay normally associated with the need for cooling and reheating of the oil condensation pump.

Metropolitan-Vickers, Ltd., Trafford Park, Manchester.



A krypton-xenon-filled Sieflash Tube suitable for high-speed photography and high-definition stroboscopic work. The range includes tubes giving an intense flash of light with a duration of 200-300 μsec, and a type with an effective flash duration of 1-2 μsec.

Siemens Bros., Woolwich.

Multiple Oscillograph Recorder

The multiple recorder is intended for use in industrial and traction test work and is designed to record photographically four cathode ray traces on a 70 mm. film.

It consists of a model 440 twin double beam tube unit and a model 430 drive unit operating a model 423 film camera or model 422 drum camera.

Three tube units may be mounted one above the other with their respective cameras to provide a maximum of twelve records to be photographed simultaneously on three separate 70 mm. films driven by a single camera drive unit.

The model 423 film camera unit may be replaced by a model 422 drum camera operating from the same drive, with variable speeds. The camera is suitable for 35 mm. or 70 mm. film 50 cm. long and capable of film traverse speeds of from ½ mm. to 25 metres/sec.

An electronic control unit is used for synchronisation at high speeds.

1049 Industrial Oscillograph

This instrument is designed specifically for the industrial user whose main interest lies in the measurement of low frequency phenomena. It consists of a double beam tube unit, time base, D.C. amplifiers and internal power supplies.

The trace is presented on a flat screen double beam tube normally operating at 2 KV, with provision for 4 KV operation for transient recording. Signals are normally fed via the amplifiers, with provision for input voltage calibration.

The time base is designed for repetitive, triggered or single stroke operation and is D.C. coupled throughout. Time measurement is provided by a directly calibrated control with time scale ranges from 1.5 seconds to 150 microseconds.

Stabilisation against mains variations up to ± 10 per cent. is provided for the amplifiers and cathode ray tube supplies and long-period stability is reached within 5 to 10 minutes from switching on.

A. C. Cossor, Ltd., Highbury, N.5.

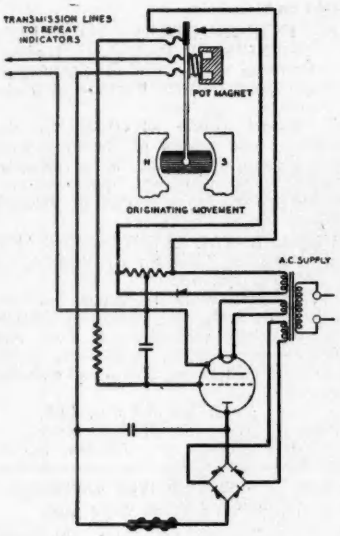
Frequency Standard

Developed for the geophysics department at Cambridge as a means of timing pendulum apparatus, this standard has an accuracy of better than 1 part in 107. It can be operated from A.C. mains or batteries.

The oscillator is of the bridge-stabilised type generating 100 Kc/s. and incorporating a GT-cut crystal. The temperature coefficient of this cut is a minimum and it is possible to correct by the use of a temperature chart instead of using the thermostatically controlled oven.

The output is applied to a frequency divider, giving outputs of 10 Kc/s. and 1 Kc/s., both stabilised. A 600 ohm output impedance is provided by a cathode follower.

Standard Telephones and Cables, Ltd., Connaught House, W.C.2.



The Electronic Repeater*

The electronic repeater (Fig. 1) is employed for distant indication over G.P.O. lines of variable physical quantities.

The varying quantity is arranged to exert a torque proportional to its value on an arm carrying a coil and a contact. The coil works in a pot magnet and the contact, which is on the end of the arm, works between two fixed contacts. The coil is in the anode circuit of a triode valve, this circuit being completed through the distant indicators and recorders which are connected electrically in series. The contact carried by the arm is connected to the grid of the valve while the two outside contacts are carrying positive and negative biasing voltages respectively to alter the anode current of the valve as required.

The current through the coil is normally such as to provide an equal and opposite torque to that provided by the quantity under measurement. But if the quantity changes, and hence the torque, then the arm is moved over and one of the biasing contacts is made; the anode current is thereby increased or decreased as required until the centre contact again moves clear because the two torques are again balanced. A condenser and resistance are connected across the grid circuit of the valve to provide storage of the required biasing voltage. The system thus provides a D.C. current in the transmission lines which is proportional to the physical quantity being indicated.

* *Patent Pending*

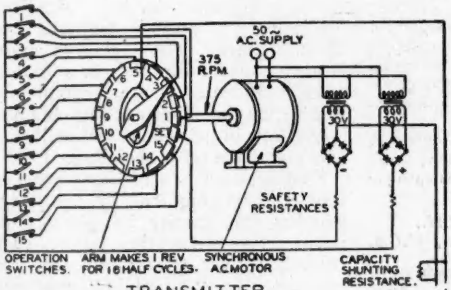


Fig. 1 (top). Diagram of electronic repeater circuit

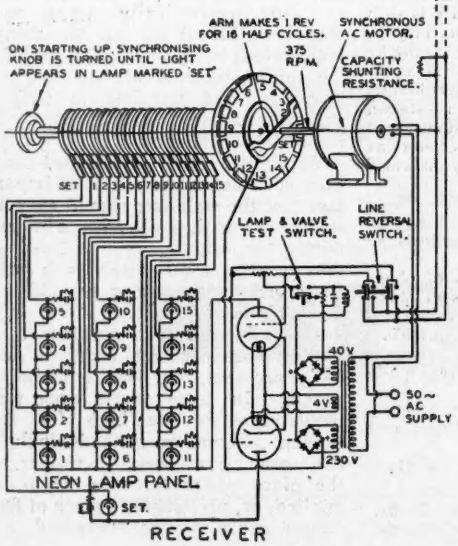


Fig. 2 (lower left). Circuit of the "Multiscope" for indicating position of switches, etc.

Evershed & Vignoles, Ltd.

The Multiscope

The multiscope (Fig. 2) provides simultaneous indication over one pair of wires of the transitory condition of fifteen two-position mechanisms such as switches or on-off valves.

The transmitter at the sending end is a synchronous motor driving a wiper arm over a faceplate having sixteen studs. The arm is connected to one wire of the transmission line while the studs are connected through the operation switches, the condition of which is to be indicated, to a D.C. supply the other side of which is connected to the other wire of the transmission line.

At the receiving end there is another synchronous motor driving an arm round studs on a faceplate. These are connected through individual neon lamps to the anode of a triode valve, while the wiper arm is joined to the positive H.T. supply for the valve. The incoming transmission line is connected in the grid circuit of the valve which therefore becomes conducting or non-conducting according to whether the D.C. voltage is being fed from the transmitting end or not.

When the valve is made conducting, then the neon tube concerned will strike and it is arranged to remain struck for the rest of the cycle of the wiper arm by placing a suitable condenser and resist-

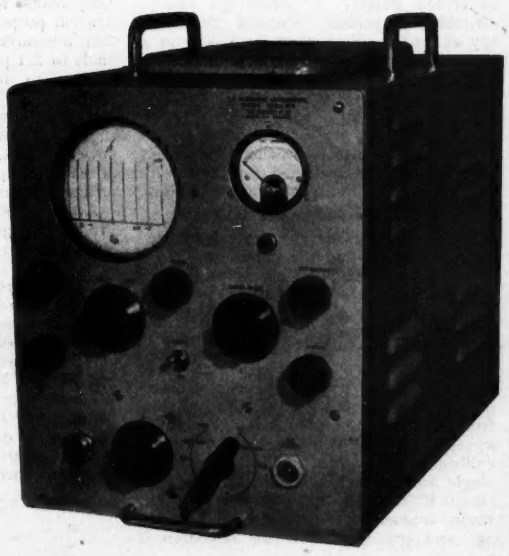


Fig. 3 (right). Plessey I.F. Alignment Oscilloscope.

ance across it. This ensures continuous indication.

Synchronisation may be checked by the use of the sixteenth stud which is fed from a separate D.C. supply reversed in polarity from that energising the other 15 studs, a second triode valve at the receiving end being provided for this circuit. The receiving end faceplate is rotated by means of a knob until the check neon is illuminated when the two ends will be in synchronism.

(*Marchment's Patents Nos.* 510551 & 516841)

Eversbed and Vignoles, Ltd.,
Acton Lane Works,
Chiswick, N.W.4.

Frequency Synthesiser, Type TD.2100

A crystal controlled frequency standard with an accuracy of 3 parts in 10^7. It is capable of standardising frequencies over the range 500 c/s. to 10 Mc/s. direct, and by harmonic extension to 300 Mc/s. Any Kc/s. interval between 2 Kc/s. and 10 Mc/s. interval between 2 Kc/s. and free of spurious frequencies to give an output of 0.1 volts across an 80 ohm lead with an accuracy of 3 parts in 10^7. Mixing and filter arrangements are provided, giving direct reading facilities, and the procedure for obtaining any frequency is reduced to setting switches and tuning filters. The ultimate frequency reference is a 100 Kc/s. G.T. cut crystal.

(See H. J. Finden, Frequency Synthesiser, I.E.E., *Jour.* Vol. 90. Part III. No. 12).

Vibrator Test Equipment, Type TD.2180

This equipment has been designed for the purpose of checking the accuracy and performance of vibrators. The test set is suited for sample tests and design work and is capable of giving accurate measurements of vibrator characteristics. Wave form is indicated on a cathode ray tube unit which gives pictures of both primary and secondary voltages. Switching efficiency is indicated on a meter which is calibrated directly in percentage and is switched for primary contacts or secondary contacts. Frequency is shown on a meter calibrated directly in cycles, and is standardised against the 50-cycle mains by a push button switch.

The panel is fitted with standard transformers for 2 V, 6 V and 12 V which are selected by means of a switch. Similarly the gear can be switched for tests with synchronous or non-synchronous vibrators.

I.F. Alignment Oscilloscope (Fig. 3.)

An instrument for the tracing of true response curves and the production alignment of I.F. circuits on a long persistence calibrated cathode ray tube. A variable speed frequency modulated oscillator is fed to the receiver through a buffer valve and calibrated attenuator. The buffer is also coupled to a mixer with local oscillator, allowing a change in mean frequency, and a circuit used to provide, from the mixed output, a D.C. horizontal sweep linear with frequency. A crystal calibrator gives spot calibration and a single valve provides stable D.C. amplification of the receiver diode signal. The mean frequency can be varied between 450 and 475 Kc/s. and the deviation is ± 20 Kc/s. The deviation speed is controllable between 1 and 20 c/s. The response of band-pass circuits can be studied on a cathode ray tube at such a speed that no erroneous results are caused by the time constant or "Q" of the circuit and so the tube-picture is identical with the response curve plotted by the usual static methods. This oscilloscope has been used with great success in the production testing of commercial radio receivers, in which case a mask can be fitted with a standard response curve to which the receiver can be aligned very rapidly. It is ideal for the alignment of high class receivers using variable selectivity, and crystal gate filters.

The Plessey Company, Ltd.,
Vicarage Lane,
Ilford, Essex.

Thermocouple Recorder

This will record temperatures up to 1,500° C. with a full scale deflection on the recorder of ± 10° and a probable overall accuracy of ± ¼° at the higher temperatures. It is fundamentally a D.C. feedback galvanometer amplifier with a photo-cell but contains several patented features which considerably improve its stability and performance.

A protective device is incorporated which automatically cuts off the supply if the illumination fails on the photo-cell and in addition a reference voltage is provided from a standard cell in the D.C. amplifier circuit.

Also exhibited were a toluene regulator, resistance thermometer controller, cold junction controller, and thermocouple controller.

Sunvic Controls, Ltd.,
Kean Street, Aldwych, W.C.2.

Student Electrical Bridge Components

Pye student electrical components fill a need for a compact, inexpensive series of components for educational and demonstration purposes. Their accuracy is such that measurements of unknowns may be made to ±1 per cent. They may readily be set up to form Wheatstone, Maxwell, Owen, Hay, Schering and other bridges for the measurement of resistance, capacity, inductance, time constants, and power factors. The internal connexions of each component are clearly indicated on the top panel.

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4. Decade resistance box units of ohms.
5. Potentiometers 100, 1,000, 10,000 and 100,000 ohms continuously variable.
6. Ratio box-double 1 : 10 : 100.
7. Twin battery/galvanometer push-button unit.
8. Rectifier bridge unit (for A.C. bridges).
9. Double 0.2 μF fixed condenser unit ± 1 per cent.
10. Resistance box multiplier for Owen bridge.

Pye Ltd., Radio Works,
Cambridge.

Books on Electronics

AN INTRODUCTION TO ELECTRONICS: By Prof. R. G. Hudson. Professor of Electrical Engineering at the Massachusetts Institute of Technology. 15s. net.

A logical course of study on the properties and control of electrons, with well illustrated descriptions of recently developed apparatus and appliances employing electronics and used in industry and elsewhere.

FUNDAMENTAL ELECTRONICS AND VACUUM TUBES: By Prof. A. L. Albert. 25s. net.

A non-mathematical account of the subject. It deals with sources of electron streams, their utilisation in diode and multi-electrode tubes, amplifiers, oscillators and modulators, photo- and cathode-ray tubes.

Macmillan and Co., Ltd.,
St. Martin's Street,
London, W.C.2.

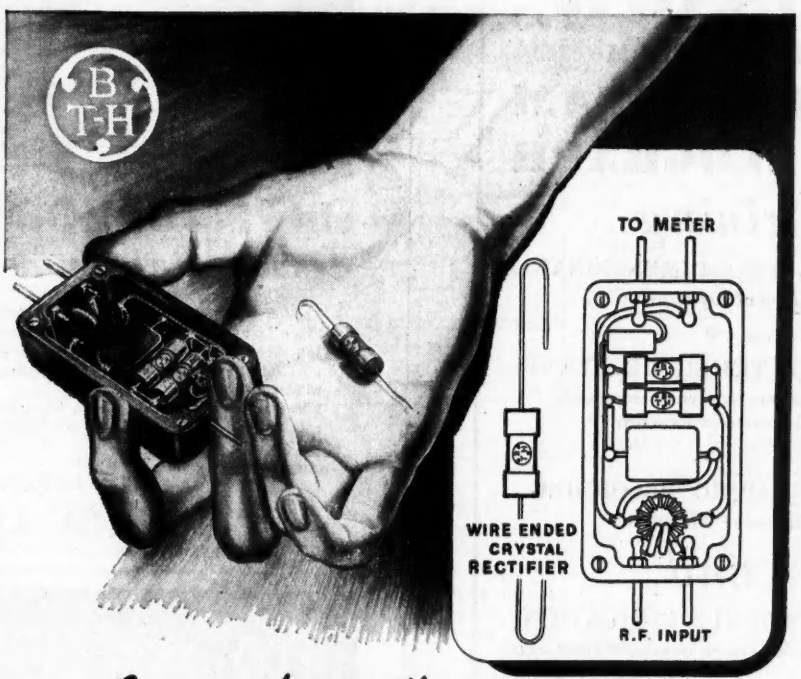
New Types of Silver Coatings

(*Continued from page* 194)

thousandths of an inch thickness silvered both sides is a perfect condenser material having excellent insulating properties, superior to those of mica. The saving in space is also considerable and, in addition, such condensers are completely flexible, as the silver coating obtained is perfect in adhesion and will not break or flake off on bending.

Coatings for condensers are, of course, best applied by spraying, whether the carrier be plastics or mica. Even for the latter, such colloidal silver preparations as, for instance, the "Elargols" prepared in these laboratories offer substantial advantages as the silver coatings are not only mechanically strong and may be soldered to, but the firing temperature being reduced to 300° C., the mica preserves all its original properties and the loss in weight usually occurring around 500° C. is completely eliminated.

With silver coatings obtained from such colloidal materials, it is important that the stabiliser should evaporate last so that the colloid is not broken during the initial stages of heating, thus ensuring a completely even coat. Only such coatings may be soldered to. This is accomplished either with argent solder or with a solder containing 35-40 per cent. cadmium and 60-65 per cent. zinc, which melts at 120° C. In cases where even this temperature is too high for the carrier, alternative methods include the spraying of metallic copper to the place where soldering is to be applied, or, preferably, a piece of fine copper gauze may be interposed.



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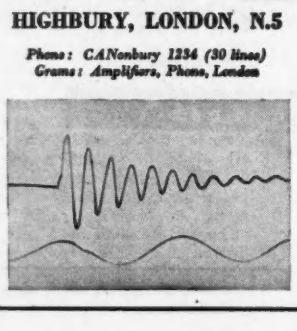

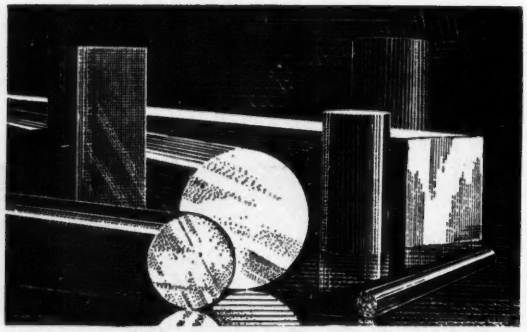

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Velocity Modulation

Part 2 of a paper read before the Electronics Group of the Institute of Physics

By J. H. FREMLIN, Ph.D., F.Inst.P.*

IT has been shown that in klystrons and tubes of the Heil type the starting current depends on the bunching efficiency H. In such systems a large increase in H can only be obtained by increasing greatly the drift-tube length and this soon results in great practical difficulties, particularly in focusing the electron beam.

A different mode of obtaining bunching was suggested by Hahn and Metcalf[6] in a paper published in 1939. Instead of passing the velocity-modulated beam across a second gap they proposed to obtain the energy transfer in the same gap as the modulation by returning the electron beam through it for a second time. Then an oscillator with a single resonator and only a single gap becomes possible. They suggested two ways in which the initially velocity-modulated beam can be made to produce a current-modulated beam.

In the first, which may be termed the method of phase-selection, the beam is allowed to fall on a plate at cathode potential. Then the electrons accelerated in their passage through the gap will be able to reach the plate and be collected, while those decelerated will be reflected. Thus groups of electrons half a period long will be returned and if distances and voltages are correctly arranged these will all be retarded in their second passage through the gap and hence do work on the R.F. field. In the absence of a spread of initial velocities the selection might be complete for infinitesimal R.F. modulating voltages and the starting current would be zero. In practice there is a spread so that at low levels the separation is proportional to the R.F. voltage and a finite but still very small starting current is obtained. The practical disadvantage is that at any reasonable amplitude secondary emission by the accelerated electrons begins and changes the whole operation of the system.

A system which actually used secondary emission to produce the desired pulses of current was worked on by Cooke, at Oxford, in the early part of the war. Here the collecting plate was made slightly positive with respect to cathode, the potential being such as to give the greatest rate of change of secondary emission coefficient with primary velocity. Thus the faster electrons give rise to more secondaries and the phase of return of the resulting concentrations of secondaries is adjusted as usual to get as much work out of the electrons as possible. At first sight this scheme seems very attractive, as the starting currents are extremely small. If a large secondary-emission coefficient is used the primary beam might be quite small and easy to focus and one might feel that no equivalent of over-bunching would arise. Unfortunately, at short wavelengths we cannot keep transit-time small, so that a good deal of ordinary bunching of the primary beam occurs for high amplitudes, tending to give current pulses at different times. Also, performance depends upon the stability of a secondary-emitting surface suffering bombardment at extremely high power density, and finally the very rapid variation of mean collector current with oscillation amplitude makes it difficult to prevent relaxation oscillations analogous to the squegging of triode oscillators.

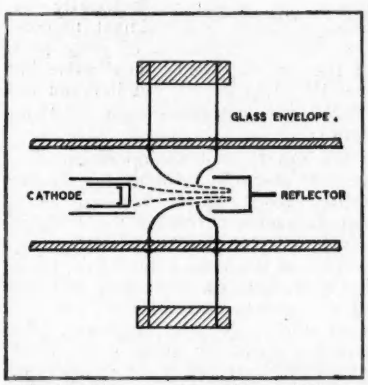

Fig. 10. Diagram of a reflex oscillator.

The best method in practice has proved to be the second method proposed by Hahn and Metcalf. In this the whole of the primary beam is reflected back through the resonator by an electrode maintained at a high negative potential with respect to cathode. This type of tube was worked on by R. W. Sutton, of the Admiralty Signal Establishment, and by E.M.I., and has been the basis of practically all the beating oscillators used in radar receiving sets throughout the war. In Fig. 10 is shown a system of the type concerned. Since no electrons ever reach the reflector secondary emission complications cannot occur.

The mechanism of bunching can then take place in either of two ways, according to the distribution of the retarding electric fields. In Fig. 11 are shown various possible types of potential distribution between resonator and reflector. If we have a constant retarding field, corresponding to the potential distribution of Fig. 11a, the faster electrons go farther and take longer, so that bunches are formed by the overtaking of the fast by the slow. This is, of course, analogous to the behaviour of a ball thrown vertically upwards; the faster it is thrown the longer it takes to come down. An excellent mechanical analogue to the system using a water jet was shown by W. J. Scott, at the Physical Society Exhibition, in January, 1946.

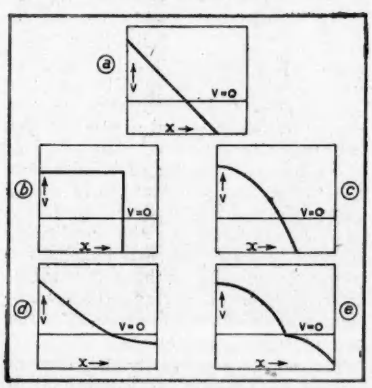

Fig. 11. Distribution of potential in various forms of retarding field.

* University of Birmingham.

If, on the other hand, we have a distribution of the form of Fig. 11b, the faster electrons return first as in the case of balls thrown against a wall.

Intermediately one could, of course, have fields giving little or no bunching; for example, if the potential falls parabolically, as in Fig. 11c, the retarding field will be proportional to distance from the gap and electron trajectories will be parts of a simple harmonic motion and thus be isochronous whatever velocity-modulation they may have undergone. Such a field might be useful in the secondary emission type of oscillator though no attempts to use such a field seem to have been tried, probably owing to the impossibility of combining it with any electrostatic form of focusing.

With fields of the form 11a or 11b we still have the same difficulty as in a klystron of obtaining a large bunching efficiency H without at the same time making the tube very large and getting overbunching at very small amplitudes. We have, however, now a further variable. A field of the form shown in Fig. 11d is easily obtained with a reflector like that shown in Fig. 10. Then H depends on the rate of change of transit-time with input velocity at the reflection point when $V = 0$. This depends on $\frac{\delta V}{\delta x}$ at $V = 0$, which can easily be made small even though the distance to the reflector is itself quite small. This also is the form of field required for electrostatic focusing.

By such means the starting current may be made so small as to be almost unimportant even at 3 cm. wavelength with a high voltage. Thus the E.M.I. tube KRN2, which operated at 1,000 volts for 3.2 cm., had a starting current of only a milliamp or so.

We still have the overbunching difficulty. This could in principle be avoided by use of a field of the form shown in Fig. 11e, when retarded electrons are isochronous with one transit-time and accelerated electrons are also isochronous with a transit-time half a period greater. Here again, however, magnetic focusing would be required and this is liable to lead to a very large noise level in the oscillator output owing to the existence of electrons which travel backwards and forwards a very large number of times, sometimes gaining and sometimes losing energy, before collection.

One more important property of velocity-modulation oscillators remains to be discussed; the fact that small changes of frequency may be obtained electrically without any mechanical adjustment of the resonant circuit whatever. The mechanical dimensions may, of course, be adjusted electrically by using electron bombardment to control thermal expansion of some part of the circuit direct, or of some bimetallic strip device, but it is not intended to consider such systems here.)

We can look at the operation of a velocity-modulation oscillator as resulting from the development of a radiofrequency current at the working gap in antiphase to the radiofrequency voltage at the same point. This, then, has properties corresponding to those of a negative resistance in parallel with the gap. If, however, the bunches arrive not quite in the right phase they will induce a component of current in the resonators in quadrature with the voltage. If the bunches lag *behind* the proper phase to give a pure negative resistance, this current will add to the normal resonant quadrature current flowing in the resonators and will have exactly the same effect as if we had added a small extra capacity to the resonator, *i.e.*, the resonant frequency of the system will be lowered.

Similarly, if the bunches lead the correct phase we are effectively decreasing the capacity and hence raising the frequency. The amount of the frequency change depends upon, firstly, the ratio of the extra induced quadrature current to the R.F. voltage, *i.e.*, to the value of the equivalent added capacity, and secondly, on the effective capacity already present in the circuit. It is desirable to emphasise that the frequency change is not a kind of forced oscillation at a frequency different from that of the resonator. This would depend on the Q of the circuit, not on the capacity. If we had a resonator of infinite Q a small quadrature current fed in would still change the frequency perfectly well, without affecting the amplitude, and not merely change it but change it instantaneously without any intermediate interval during which transient phenomena might occur as in the case of forced oscillations.

The effect can easily be demonstrated by the use of a mechanical oscillating circuit consisting of a simple pendulum. An extra restoring force may be applied for a short part of each cycle in quadrature with the pendulum velocity, *i.e.*, near the phase at which the gravitational restoring force is a maximum, by letting the pendulum swing against a light spring. It will be found that the pendulum period is at once reduced without significant change of amplitude. If applied only for a brief time the system may be used as a very convenient phase-adjustment. With the help of a magnet and a pendulum bob of magnetic material an increase of period can be obtained, though with an ordinary steel bob eddy current damping leads to an appreciable fall in amplitude.

To return to the velocity-modulation tube, the method of changing the phase at which the bunches traverse the working gap is simply to change the mean transit-time in the drift-tube or reflecting space. This is done in a klystron or coaxial-line oscillator by changing the H.T. voltage, and in a reflex tube more conveniently by changing the reflector potential. In the standard reflex oscillator used in radar receivers a change of ± 10 to 15 Mc/s could be obtained in this way in the centimetre wave band before the power output dropped to one-half, and particularly at 3 cm. was almost indispensable for rapid automatic frequency control.

The theory of this, too, has been worked out, at least for the less complicated systems, and it is interesting to note that for similar conditions the *absolute* frequency change obtainable is roughly independent of mean frequency, so that the proportional change might be made quite large at low mean frequencies. To get a large frequency swing by such means it is desirable to keep the total equivalent circuit capacity as low as possible, the operating current as high as possible and the bunching efficiency as great as possible. The best circuit so far available to meet the first point is that shown in Fig. 9, in which the gaps are effectively in series in a single circuit and the total capacity is of the order of half the capacity across one gap. Such circuits are, however, inconveniently large, except at the very shortest wavelengths, and a quarter-wave coaxial-line circuit (such as would be obtained by bisecting Fig. 5) can give very useful results.

A particularly large frequency change is obtainable if such a system is used as a reflex oscillator so that

we have effectively two modulating gaps and two working gaps. Changes in the region of 10 per cent. in frequency have so been obtained. The limits are, of course, set by the fact that if the bunch leads or lags behind its normal value too much it does not transfer so much energy, and after a phase change of 90° would not transfer any energy at all.

The author wishes to express his indebtedness for such knowledge as he has of velocity-modulation to the past and present members of the electronics group at Standard Telephones and Cables, with whom he was previously associated under the direction of Mr. E. H. Ullrich, and especially to Messrs. D. P. R. Petrie, C. Strachey, P. J. Wallis and Dr. S. G. Tomlin, who were between them responsible for the development of a great part of the quantitative theory on which this outline has been based.

The excellent degree of collaboration between different laboratories working on velocity modulation tubes during the war was also of incalculable value and a list of those who have helped to improve the author's understanding of the subject would be practically coextensive with a list of those working upon it. As it would be impossible to single out one rather than another it is desired to offer general thanks equally to everyone concerned.

The work on which this paper is based was carried out under research contract for the Director of Scientific Research, Admiralty, and the author wishes to thank the Board of Admiralty for permission to publish.

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JUNE MEETINGS

The Institution of Electrical Engineers

Southern Centre

Date: June 18. Time: 7 p.m.
Held at: The Royal Aircraft Establishment, Farnborough.
Lecture: "Frequency Modulation."
By: K. R. Sturley, Ph.D., B.Sc.
Hon. Secretary: W. M. Read, The Oaks, Ashurst, Southampton.

The Institute of Physics

Electronics Group Summer Meeting

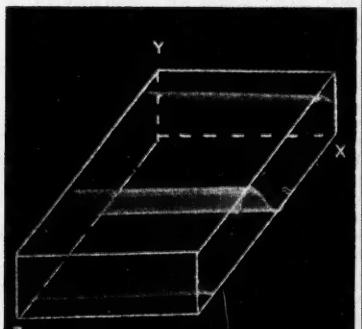
Date: June 14. Time: 2.30 p.m.
Held at: Fyvie Hall, The Polytechnic, 309, Regent Street, London, W.1.
Discussion on: "Thermionic Emission from Oxide-Coated Cathodes."
"Review of Experimental Work."
By: Dr. F. A. Vick, O.B.E., F.Inst.P.
"Factors limiting Current Density."
By: D. A. Wright, M.Sc.
"The Chemistry of Oxide-Coated Cathodes."
By: A. J. H. Darlaston, B.A., F.C.S.
Hon. Secretary: A. J. Maddock, "Sira," South Hill, Chislehurst, Kent.

July Conference

A Conference is being arranged on "Applications of Radioactive Tracer Elements in Physics Research and Industry," from 2 p.m. on Thursday, July 10, to noon on Saturday, July 12, in the Physics Department of Manchester University. Dr. J. D. Cockcroft, C.B.E., F.R.S., Prof. F. Paneth, F.R.S., and Mr. D. H. Wilkinson, will give the opening papers. The Conference will be open to anyone interested, without charge, but admission will be by ticket only.

Further particulars may be obtained from the Conference Secretary, who will be pleased to receive suggestions for papers or contributions to discussions.

Conference Secretary: *W. J. Meredith, F.Inst.P., Christie Hospital and Holt Radium Institute, Wilmslow Road, Manchester, 20.*



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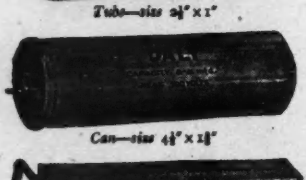

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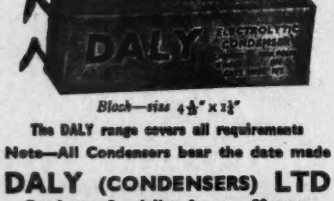

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BOOK

Radio's Conquest of Space

D. McNicol (Past President, I.R.E.) 364 pp. published by Murray Hill Books Inc., N.Y. $4.00.

Mr. McNicol has grown up with radio engineering. He constructed a transmitter and receiver in 1900 and was president of the Institution of Radio Engineers at a time when the full possibilities of radiocommunication were being realised.

In " Radio's Conquest of Space," he has combined his own personal recollections with a carefully writtten account of all the important steps which led to the world-wide use of radio.

It is in reading a book of this type that one realises how young radio really is. The mind recalls the hours spent in finding the most sensitive spot on a crystal detector, the careful adjustment of filament current in the early bright emitters, and the weird and wonderful designs for honeycomb coils. And even in the short time that has elapsed since Marconi sent his " S " over the Atlantic, the wheel has come round—the crystal detector, the reflex circuit are with us again. Soon someone will reinvent the coherer, and we shall say " This is where we came in."

The author is at pains to mention all those who made their contributions to the advancement of the science. He mentions that one of the earliest publications on wireless telegraphy appeared in 1898—a small book by Richard Kerr, which must now be a very rare collectors item. An equally rare item, which may be news to the author, is a privately printed " History of Wireless Telegraphy " written by Silvanus Thompson in 1911 in connexion with the Lodge-Muirhead petition for the renewal of the patent of 1897 for " syntonised telegraphy ": a year before Marconi's use of tuned circuits.

In his concluding chapter " The Expanding Sphere of Radio " the author brings us to the development of radar and holds the balance well between the British and American contributions to this branch. This spirit of fairness is manifest throughout the whole book. Dr. McNicol has set out to trace the evolution of radio as a disinterested observer, paying tribute where tribute is due, and free from any national bias.

How different from the partisan writings of some of his fellow-countrymen, who are so intent on claiming " firsts " that they refuse to recognise that science has no nationality and that the greatest scientists have always been the most modest!

This is a good book and an authoritative book, and will be read with pleasant memories by all old-timers in the radio industry.

Communication Through the Ages

A. Still, M.I.E.E. 194 pp. Murray Hill Books, $2.75.

Dr. Alfred Still's book on Communication through the Ages covers the field in in wider sense, and leads us to radio through " drums, fire, and smoke," rays of light, and finally, sparks of electricity.

In his opening chapter he defines his aim as not merely to tell the story of the conveyance of messages through the ages, but to discuss the whole question of communication between man. After telegraphy came speech, after speech came vision, after vision—what? " The more whimsical radio engineer might discover something new . . . . He might discover a new manner of communication, another and hitherto undreamed-of channel through which civilisation could advance."

The last chapter on Communication without Words touches on the subject of telepathy, on which the author remarks " it can be stated without fear of contradiction that we know nothing whatever about it," and then contents himself with a brief survey of the experiments to date.

Throughout his lucid account of the development of communication Dr. Still is always ready to add enlivening touches to the narrative.

He also has something to say about the partisan claimant for honours for his country: " Let us by all means give credit to the pioneers and glorify those who deserve glorification, provided always that this can be done without unduly emphasising the symbolic virtues of the coloured bunting to which they have sworn allegiance."

In the chapter on " Pioneers," Henry, Morse, Cooke, and Wheatstone, the author echoes the generally accepted view that without Cooke's aid it is doubtful whether Wheatstone would have made a success of the telegraph, although as in the case of the Bridge, most of the credit was given to Wheatstone himself.

In reading through a book of this type it is difficult to refrain from quoting (and reading aloud, if one has an audience) many of the happier phrases. A last one will suffice to sum up the state of the art at the present time:

" Apart from being admirably suited to the purpose of spreading unrestricted propaganda, disseminating political falsehoods, and enriching advertisers, radio broadcasting serves many a useful and laudable purpose,"

Both these books are worth buying and keeping—the first for a fair and accurate account of the growth of our profession and the second for its entertaining style and stimulating treatment.

G. PARR.

REVIEWS

"Drafting for Electronics"

L. F. B. Carini. (McGraw-Hill Book Co. Inc.). xi plus 211 pages. 186 figures. $2.50.

Owing to the increasing complexity of modern electronic apparatus, the importance of clear circuit diagrams, in which the primary aim is the ease of understanding the operation of the circuit, is becoming more and more widely recognised. As a result of this, the Services have issued a book of standard symbols which contains, for the first time, a set of "recommendations to draughtsmen" regarding the *arrangement* of the symbols in a diagram.

The title of the book under review suggested that it might contain similar recommendations, modified necessarily by the difference between American and British conventions. The reviewer, having been actively concerned with the preparation of the British publication mentioned above, was disappointed when he found that the author sets out only to show draughtsmen with little knowledge of electronics how to draw circuit-diagrams neat enough to meet with the approval of a non-electronic drawing office.

Two quotations will show this:—

p.70. "The graphic draftsman should strive to observe certain accepted rules . . . Of prime consideration among them is *background area*. In a schematic drawing of a circuit this refers to the regularity of spacing about each of the graphic symbols."

p.103 (discussing parallel leads) "In extending the common connecting leads (ground, B + and bias) that must traverse the lower section, an equality of spacing should be maintained between them to afford *uniformity and ease in tracing*." (The italics are the reviewer's).

It is universally agreed that a number of *equally spaced* leads is very confusing; the author has thus subordinated clarity to drawing-office conventions.

Half the book is devoted to general drawing-office methods such as the use of drawing instruments, etc. A long chapter on the use of various kinds of graphical representation (called surprisingly "Graphical Integration") is included.

The rest of the book contains the special information appropriate to its title. This part will be examined in more detail.

A chapter on symbols lists the recommendations of the American Standards Association (A.S.A.). One general difference between B.S.I. and A.S.A. symbols is that the latter make use of a uniform thickness of line for drawing the connecting leads and the symbols (for example, anodes and condenser plates are *not* thick). This A.S.A. convention could be used with advantage in this country for preliminary sketches, as it saves much time.

Another point of difference is that the A.S.A. allows the configuration of a cross and dot for showing that leads cross in contact, while B.S. 530-1937 forbids this and insists on "staggered cross-roads." (See sketch.) Incidentally, the B.S.I. rule is by no means sufficiently well-known in this country.

The authors' attitude towards the duties of the circuit-draughtsman is made clear by the following quotation from p.118.

He is discussing the convention (used by some American Power Engineers), of drawing the principal voltage-supply lines in order of their potential differences above earth, as compared with that of drawing the H.T. line below earth (used by American Radio Engineers). "For the sake of standardisation, the procedure as applied in radio practice is to be preferred. This is also the most simple and expeditious for the draftsman, who should not have to worry over the matter of maintaining correct potential levels as he continues to expand his circuit. After all, he is not paid to be an electrical engineer."

Apparently the author does not envisage the re-arrangement of a drawing by someone who understands the operation of the circuit.

Some examples of the re-drawing of rough sketches are given. In one of these (on page 100) some good points in the sketch are spoiled in the final drawing.

An unfortunate mistake has been made in the re-drawing of Fig. 123—a phase-sensitive rectifier circuit—in order to avoid a triple cross-over of leads. The associated electrodes in a double diode have been accidentally transposed and the "improved" circuit won't work.

The author persistently states simple facts in an involved and grandiloquent manner. For example:—

(p.136) "For the matter of reference, specific information, whether categorical or hypothetical, when compiled for factual use and upon which an inference is based, is known to the technical man as *data*."

This habit sometimes leads him astray when, for instance, describing polar-co-ordinate paper, he says:—

p.156 "The origin, being consistent to the centre, is the basis for measurements that are located as points within the periphery. Since a point is noted according to its distance from the origin O, the location must also produce the equivalent of a scalene triangle with the O axis, which is the basis for calculating complex values."

The book has yet to be written which will tell its reader how to draw diagrams with the sole object of explaining the operation of circuits.

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High-Power Television Transmitters

(*Continued from page* 184)

the attenuation of such cables is usually high compared with concentric copper tube and open wire types of transmission line, being roughly 0.3 db. per 100 ft. at 50 Mc/s., as compared with a probable 0.1 db. per 100 ft for the two latter types. Furthermore, the power rating of commercially available cables appears to be restricted to a maximum of some 8 to 10 KW at 50 Mc/s. which rules out their immediate use in the higher power field. The present choice in this field thus lies between the concentric copper tube feeder with a Z_o in the region of 70 to 80 ohms and either a 4-wire balanced or a 5-wire unbalanced open wire line with a Z_o in the region of 300 ohms.

The construction, routeing and supporting of lines of these three types requires careful consideration if serious impedance irregularities are to be avoided; the difficulty is probably more pronounced in the copper tube concentric type due to the necessity of joints and junction boxes and of discretely spacing the relatively large number of conductor spacing insulators along the length of the line. It is therefore likely that serious consideration will be given to the use of open wire lines both on the score of more suitable technical characteristics and cost of construction. For example, an arrangement which shows considerable possibilities is an open wire line of the 4-wire balanced type in which the number of conductor spacing insulators and supporting points is reduced to a bare minimum by stringing the line vertically, under considerable tension, down the inside of the mast structure. The main impedance irregularities can then be restricted to the point at the base of the mast where the line changes its direction from vertical to horizontal and at the insulator where the line enters the building. Some additional supports would be necessary to prevent changes on the relative disposition of the wires, due to wind, which might give rise to random modulation of the radiated signal.

A further advantage of a balanced as distinct from an unbalanced line is that in most cases the aerial itself will be some form of balanced dipole so that the use of an aerial matching transformer designed to convert from balanced to unbalanced as well as to provide the usual impedance transformation and reactance correction, is avoided.

The fact that the characteristic impedance of open wire lines is relatively high means that as a general rule the transmitter output coupling circuit would need a parallel tuned secondary, while with a concentric line or cable a series tuned secondary would be the most convenient for obtaining the appropriate value of secondary circuit Q for the bandwidth response required.

It seems fairly certain that eventually the best solution of the feeder problem lies in the development of a semi-flexible low loss cable having a characteristic impedance of some 50 to 60 ohms, which is maintained uniformly throughout its length, and capable of transmitting a power of the order of 50 KW continuously at 60 Mc/s. when feeding an accurately matched load.

It should be mentioned here that while it is practicable to design an aerial and transmission line system which presents to the transmitter output a load impedance which remains a constant resistance within limits of between 5 to 10 per cent. over bandwidths of the order of 3.0 Mcs., it is inevitable that with wider bandwidths the impedance will show a substantial variation towards the extremes of the sideband range.

The form of the load impedance/frequency characteristic presented to the transmitter is important from the point of view of obtaining the best overall performance conditions in respect to the sideband frequency response from the output stage.

A general consideration of the problem indicates that for any given power output at the carrier frequency and given limits of impedance variation the best overall response and operating condition is obtained if the output coupling circuit is designed to be "maximally flat" (for a constant resistance termination) and the load impedance, presented to its output terminals by the transmission line, falls symmetrically on either side of the carrier frequency. Further, the reactive component of this impedance should preferably be positive at the upper and negative at the lower sideband frequencies.

Such a condition of symmetry is more likely to be obtained if any filters or matching circuits used in the transmission line system are of the band pass type constructed from line sections, while the inverting property of a $\frac{1}{4}$ wave line section can be used to convert a symmetrically rising impedance/frequency characteristic into the preferred falling one.

(*See next column*)

There are many other problems of circuit and general mechanical design which it is beyond the scope of this article to discuss. Nothing has been said of the many difficulties involved in the design of wide band transmitting aerials or the conflicting requirements of high-power wide band vision modulators. Suffice it to say that as with the transmitter itself they each require their own special technique in which substantial advances are likely now that television is once again on our screens.

Correction.

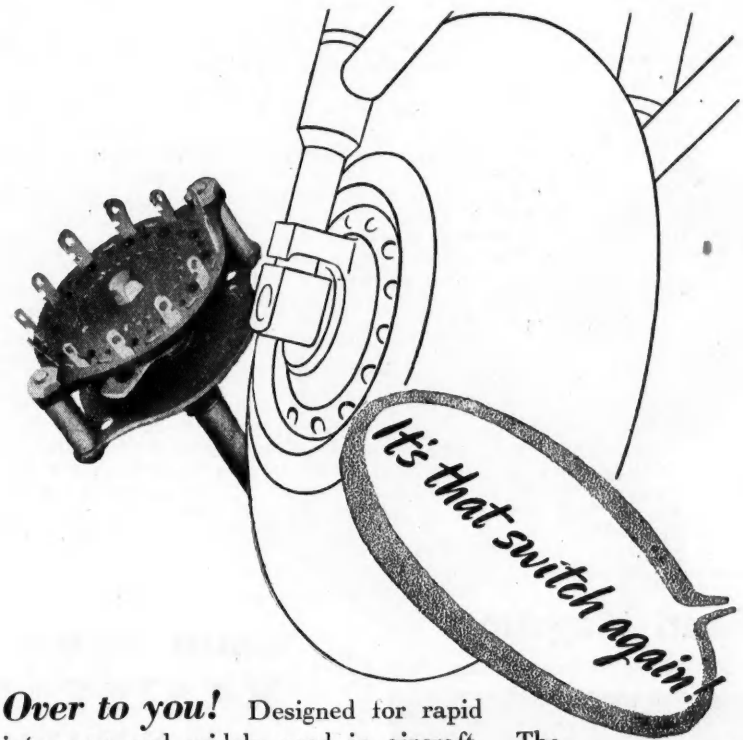
In Part I of this article the statement on Fig. 4: $Q_S = 2Q_T$ should read: $Q_T = 2Q_S$.

An Electron Multiplier Improvement

IN some types of secondary emission electron multipliers a secondary emitting electrode has in front of it an anode or collector consisting of a grid. This anode, being at a higher potential than the secondary emitter draws off secondary electrons and eventually collects them after they have done perhaps one or two oscillations back and forth through the gaps in the grid. The electrons projected through the gaps can, if the gaps are narrow, or the potential difference between the anode and secondary emitter low, return to the secondary emitter and get lost.

It has been found that this disadvantage can be overcome if the secondary emitter is provided with ribs or otherwise roughened surface, the ridges being comparable in dimensions with the distance from the emitter to the collector. The wire of the grid forming the collector may be aligned with the ridges in the emitter surface. Further, the spacing between the secondary emitter and the anode may be made smaller than the separation of the wires forming the collector. By using these features either separately or in combination it is possible to introduce sufficient change in the direction of motion of the electrons on returning towards the emitter that they can no longer reach it and be absorbed on it.

Communication from E.M.I. Laboratories



Over to you! Designed for rapid inter-com and widely used in aircraft. The Type 40/1542 is a simple two-way switch, spring biased so that it automatically returns to one position, normally used for speech. To listen the user rotates and holds in Position 2. This switch will find wide uses in civil aircraft and for inter-office communication on subsidiary stations.

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C.R.C.18

NOTES FROM THE INDUSTRY

New Company Formed by Mullard Wireless Service Co.

A new company, to be known as Electronic Transmission Equipment, Ltd., has been formed by the Mullard Wireless Service Co., Ltd. It will take over the present communications activities of Radio Transmission Equipment, Ltd., in the new laboratories and works at Brathway Road, Wandsworth, S.W.18. The products developed and manufactured will be marketed through the Communications Division of the Mullard Wireless Service Co., at Century House, which will be under the management of Mr. E. E. Jones.

The Production Crisis

A series of attractive "Production Boosters" designed for wage packet propaganda are being issued by Messrs. Pipe-Waples Services, 17 Pear Close, Colindale, N.W.9. Each "booster" for circulation among employees is intended to rivet attention on vital aspects of the economic crisis. Inquiries on official letterheads and enclosing a stamped addressed envelope are invited from business executives.

Summer School in X-Ray Crystallography

It is announced that a course will be held in the College of Technology, Sackville Street, Manchester 1, and that a Summer School will also be held in Cambridge, from September 1-12, 1947. The Manchester School will be devoted to the methods and application of X-ray crystallography as such, and the Cambridge School will be concerned with Metal Physics, and will treat X-ray methods as one of the means for examining problems of the metallic state.

Full details can be obtained from the Secretary, Extra-Mural Department, The University, Manchester, 13.

Vibrators

In the report on the Physical Society's Exhibition which appeared in last month's issue, the illustration of a vibrator was wrongly ascribed to the Wimbledon Engineering Co. The photograph was supplied by The Plessey Co., Ilford, who also exhibited vibrators.

BEAMA

The annual report of the Council of the British Electrical and Allied Manufacturers' Association for 1946-7 has just been issued. Mr. E. C. Holroyd, of Crompton Parkinson, Ltd., was unanimously re-elected chairman of the association for the session 1946-7, and Sir Harry Railing, of the General Electric Co., Ltd., was re-elected vice-chairman for the period. The new director of the association is Mr. B. H. Leeson, O.B.E., M.I.E.E., who took up office last October. In a review of the trade position the report states that in spite of shortages of materials and many other difficulties which beset the industry during 1946 progress was, nevertheless, made in electrical manufacture. The numbers employed have increased by 6½ per cent., and it is interesting to note that 480,000 workers are now engaged in the industry, of which 160,000 are on electrical engineering, 265,000 on cables, apparatus and lamps, and 55,000 on wiring, contracting and erection.

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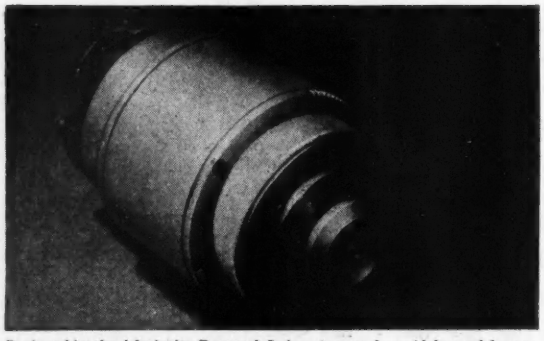

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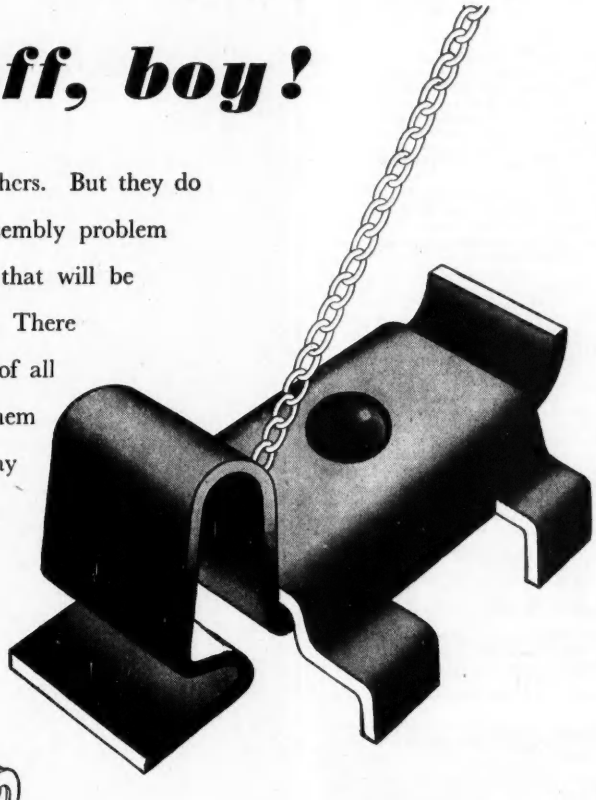

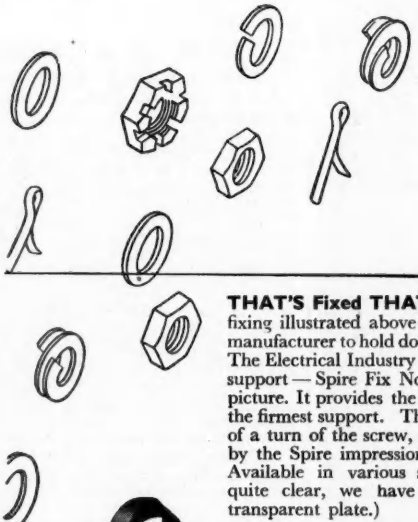

THAT'S Fixed THAT! The "doggie" looking Spire fixing illustrated above is actually made for a motor-car manufacturer to hold door trim in position.
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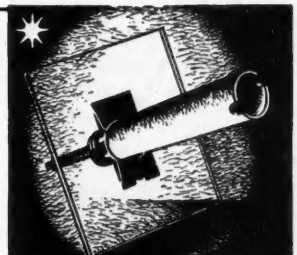

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Partridge News

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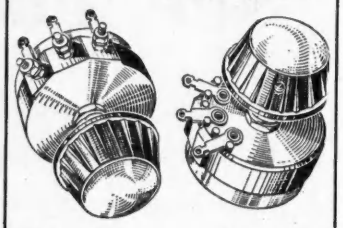

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IT IS DESIRED to secure the full commercial development in the United Kingdom of BRITISH PATENT No. 558826, which relates to radio receivers, either by way of the grant of licences or otherwise on terms acceptable to the patentee. Interested parties desiring copies of the patent specifications should apply to Stevens, Langner, Parry and Rollinson, 5/9, Quality Court, Chancery Lane, London, W.C.2.

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PHYSICISTS and electrical engineers required for work on radar and radio navigational equipment. Experience in radio research or development is essential an honours degree desirable. Several vacancies exist within the salary range £400–£900, dependent on qualifications and experience. Application forms are obtainable from the Personnel Manager, Ferranti Ltd., Ferry Road, Edinburgh 5.

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ELECTRICAL ENGINEERING manufacturers in the Midlands require engineers with specialist knowledge of electronic control circuits and equipment, must have studied communication engineering to degree standard or equivalent. Also have sound general experience in electrical and mechanical engineering and ample practical experience in industrial electronic engineering. Age 28 to 35 preferred. Reply Box 993, "Elec. Engg."

ELECTRONIC ENGINEER, degree standard, of some years experience for development of cathode ray tubes and modern transmitting valves. Write giving age, details of education and experience, together with salary required, to Box 014, "Elec. Engg."

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TECHNICAL ASSISTANT required by well-known company situated West London district for investigation of improved processes in cathode ray tube manufacture. Degree in chemistry or an equivalent qualification desirable. Industrial experience on similar work an asset. Applications, which should include full details of training, experience, age and salary expected, should be addressed to Box 031, "Elec. Engg."

LABORATORY MECHANIC required by Research Laboratory in West London area, preferably with service experience equal to tele-mechanic (H.A.A.), Class 1 or 2. Please apply in writing to British Insulated Callender's Cables, Ltd., 38, Wood Lane, Shepherds Bush, London, W.12, giving details of age, qualifications, experience and salary required.

DEVELOPMENT RADIO Engineer Designer required. Must be experienced in design connected with electronic sound equipment. Apply with fullest details of career to Personnel Manager, Miles Aircraft Ltd., Reading.

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CLASSIFIED ANNOUNCEMENTS (CONT.)

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GLASS WORKERS or Glass Blowers required with experience of hand or machine operations on glass tubing or similar work. Applicants will be graded according to ability and will have the opportunity of training for the grade of skilled glass blower. Five-day week. Application may be made in writing or in person (Monday-Friday) to Works Personnel Officer (Ref. Aa), Mullard Radio Valve Co., Ltd., New Road, Mitcham Junction, Surrey.

JUNIOR DRAUGHTSMEN, with radio or light electrical engineering experience, required by large company in East London. Reply, stating details of training, age and experience, to Box 026, "Elec. Engg."

AN ENGINEER required in North-West Kent area, age 20-30, for work on television circuits. Applicant should hold degree in electrical engineering or physics, must have a sound knowledge of pulse technique and a good background of mathematics. Write, giving full details of experience, etc., to Box M.1830, A.K. Advg., 212a, Shaftesbury Avenue, W.C.2.

YOUNG ENGINEER, with telecommunications training and capable of general circuit calculations, required as assistant development engineer in cable factory. B.Sc. or equivalent and mathematical ability essential. Age about 25, salary £400 approx. Apply Staff Officer, B.I.C.C. Ltd., Belvedere, Kent. Ref. SR/16.

PHYSICIST OR ENGINEER required, preferably with a good honours degree, with experience in research and development in telecommunications, for work on radio communication equipment. Apply by letter only, stating age, experience and qualifications, to the Director, Research Laboratories of the General Electric Co. Ltd., N. Wembley, Middlesex.

CHIEF ELECTRICAL RADIO ENGINEER with creative ideas and initiative wanted to control radio research laboratory, drawing office and development shops, covering the design and development of radio receivers and allied apparatus. First-class opening for the right man. London area. Write in confidence, giving technical qualifications, practical experience and terms required, to Box 023, "Elec. Engg."

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PHYSICIST or well qualified engineer required for specialised research work on properties or ceramics. Applicants should have sound knowledge of electronics and high frequency measurements. Apply Box 040, "Elec. Engg."

FOREMEN REQUIRED for assembly line production of good class radio receivers. Applicants must have good knowledge of modern methods of production and have served in a similar capacity. South Birmingham area. Write stating age, experience and salary required to Box 038, "Elec. Engg."

FOREMEN REQUIRED with a thorough knowledge of radio component part production including coil winding. Applicants must be capable, possess good knowledge of modern production methods, and must have held a similar position. South Birmingham area. Write stating age, experience and salary required to Box 039, "Elec. Engg."

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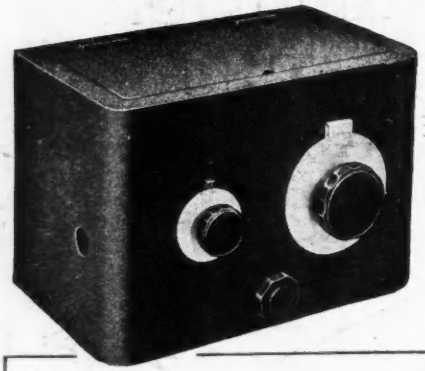

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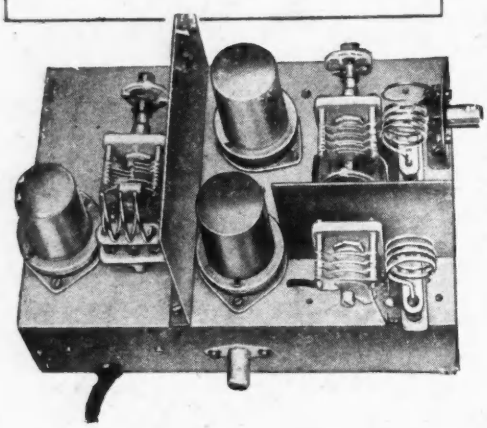

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